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Indoor evaluation of Salomon surfsuits

S.J. Davies
M.B. Ducharme

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Abstract

Salomon's Advanced Research Clothing Division contracted DCIEM to assist in development and evaluation of technical surfsuits by defining the thermal insulation properties of surfsuit prototypes and the main heat loss areas during simulated surfing activity. Thermal characteristics will be evaluated by Salomon to design future surfsuits with different insulations according to heat storage and surfing activities. DCIEM tested three prototype surfing wetsuits for thermal characteristics in two water temperatures. Each surfsuit differed in amount and location of insulation, which would affect their capacity to retain heat. Four male subjects volunteered to test six conditions between August and December 2001. Each condition included one of two water temperatures (13°C and 18°C) and one of three surfsuits during simulated surf activities. After 2 minutes of floating rest, subjects experienced 120 minutes exposure of which 72 minutes were prone arm paddling on a tethered surfboard, 24 minutes were treading water and 24 minutes were immersed rest. Arm paddling metabolic rates averaged 5.64 times rest values. Sweat accumulation was never a concern. Surfsuit fit and water movement inside the surfsuit were considered important comfort factors. NU experienced the best physiological and thermal responses but subjects complained of increased muscular effort for the posterior and medial deltoids when the non-uniform surfsuit was worn. EB was coolest especially for the lower leg but perceived exertion ratings were lowest among surfsuits due to thinner neoprene fabrics. N was similar to the enhanced boundary surfsuit yet provided marginally better protection. NU had highest rectal temperature by 0.4°C and 0.3°C in 13°C and 18°C water respectively. Subjects were slightly hypothermic after wearing N and EB in 13°C water. Average heat flux was between 30 to 50 W/m2 lower for sensors under NU's additional insulation panels except for chest, which was similar in 18°C water. Skin temperatures were 2°C higher for NU's double-insulated appendages and neck regions with other torso values 1°C higher. Thermal comfort ratings were lowest for EB and highest for NU. NU ratings of perceived exertion were highest for the first twenty-five minutes. Clothing insulation was greater for NU regardless of water temperature.

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Résumé

La Division de recherche de pointe en vêtements de Salomon a retenu les services de l'IMED pour collaborer au développement et à l'évaluation de combinaisons de surf techniques en définissant les propriétés d'isolation isotherme des prototypes de combinaisons et les principales zones de perte de chaleur lors d'activités de surf simulées. Les propriétés isothermes seront évaluées par Salomon afin de concevoir des combinaisons de surf futures ayant différentes isolations selon les accumulateurs thermiques et les activités de surfing. L'IMED a testé les propriétés isothermes de trois prototypes de combinaisons de surf à deux températures de l'eau. La quantité d'isolation et l'emplacement de cette dernière étaient différents pour chaque combinaison de façon à influer sur la capacité à retenir la chaleur. Quatre sujets mâles se sont portés volontaires pour tester six conditions entre août et décembre 2001. Chaque condition comprenait une des deux températures de l'eau (13 °C et 18 °C) et une des trois combinaisons lors des activités de surf simulées. Après un repos de 2 minutes en position de flottaison, les sujets étaient exposés à 120 minutes d'activité dont 72 minutes passées à ramer avec les bras en position couchée sur une planche de surf ancrée, 24 minutes à nager sur place et 24 minutes en position de repos immergée. Lorsque le sujet ramait avec les bras, son énergie métabolique correspondait en moyenne à 5,64 les valeurs au repos. L'accumulation de sueur n'a jamais été un problème. L'ajustement de la combinaison de surf et le mouvement de l'eau à l'intérieur de la combinaison de surf ont été jugés comme des facteurs de confort importants. La combinaison NU a obtenu les meilleures réactions physiologiques et isothermes, mais les sujets qui la portaient se sont plaints de l'effort musculaire accru des muscles deltoïdes médiaux et postérieurs. La combinaison EB était la moins chaude surtout pour la partie inférieure de la jambe, mais le niveau de fatigue à l'effort perçu par les sujets était moins élevé pour cette combinaison en raison de la mince épaisseur du néoprène. La combinaison N était similaire à la combinaison de surf à couche limite améliorée, mais a offert une protection légèrement meilleure. La combinaison NU a obtenu la température rectale la plus élevée de 0,4 °C et 0,3°C respectivement aux températures de l'eau de 13 °C et 18 °C. Les sujets souffraient légèrement d'hypothermie après le port des combinaisons N et EB dans l'eau à 13 °C. Le flux thermique moyen était entre 30 et 50 W/m2 plus faible pour les capteurs placés sous les panneaux d'isolation additionnels de la combinaison NU, sauf pour la poitrine, dont les résultats étaient similaires à ceux obtenus dans l'eau à 18 °C. La température de la peau était plus élevée de 2 °C pour les zones du cou et des extrémités à double isolation et de 1°C pour les autres valeurs du torse. Les cotes de confort isotherme les plus faibles ont été obtenues par la combinaison EB et les plus élevées par la combinaison NU. Le port de cette dernière a donné lieu au niveau de fatigue perçu le plus élevé pour les premières vingt-cinq minutes. L'isolation du vêtement était plus élevée pour la combinaison NU, indépendamment de la température de l'eau.

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Executive summary

Salomon expanded its scope of expertise by development of technical clothing for a variety of outdoor sports including surfing. The company approached DCIEM to test three prototype surfsuits for thermal characteristics during simulated surf activity in 13°C and 18°C water temperatures, and to evaluate the clothing effects on thermal responses, perceived exertions and thermal comforts. Traditional surfsuits are designed for thermal insulation without regard to which muscle groups generate most heat. Thermal characteristics will be evaluated by Salomon to design future surfsuits with different insulations according to surfing activity heat storage. All surfsuits were assembled from like panels of neoprene fabric consisting of synthetic tricots bonded to a foam core measuring 2.5 millimetres to 3.5 millimetres thick. The main differences between surfsuits were the fabrics against the skin and the amount of neoprene insulation. One surfsuit has normal synthetic tricots with 3.0 millimetre neoprene, while a second surfsuit had a piled inner tricot to possibly increase the amount of water comprising the boundary layer with the objective to increase the insulation of the suit without increasing suit bulkiness, while a third surfsuit had additional neoprene panels covering the upper legs, upper torso and arms yet worn beneath the first surfsuit. All surfsuits were developed by Salomon to provide comparable thermal insulation yet the prototype neoprene panels worn as part of the third surfsuit were developed by the authors to increase the insulation directly over active muscle groups or high blood flow regions. Four male subjects participated in the study wearing each of the three surfsuits in 13°C and 18°C water temperatures for 120 minutes exposure of which 72 minutes were prone arm paddling on a surfboard, 24 minutes were treading water and 24 minutes were immersed rest. Arm paddling metabolic rates averaged 5.64 times rest values. Subjects perceived surfsuit fit and water movement inside the surfsuit as important comfort factors. Sweat accumulation was never a concern. The ensemble with the non-uniform insulation experienced the best physiological responses and thermal comfort ratings but it was perceived as less flexible requiring increased muscular efforts for the posterior and medial deltoids. The enhanced boundary layer surfsuit was cooler especially for lower leg but perceived exertion ratings were lowest with the thinner neoprene. The non-uniform insulation surfsuit was the most thermally comfortable under the conditions tested. The additional neoprene panels worn beneath the surfsuit were responsible for the preference. Insulation for the lower body in all surfsuits needs to be maintained to ensure thermal comfort. If an ensemble had to be selected as is for comfort and protection in the conditions tested, the non-uniform surfsuit would be favourable.

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Sommaire

Salomon a élargi la portée de son expertise en développant des vêtements techniques pour une variété de sports extérieurs dont le surf. L'entreprise a approché l'IMED pour tester les propriétés isothermes de trois prototypes de combinaisons de surf lors d'activités de surf simulées dans de l'eau à une température de 13 °C et 18 °C, et pour évaluer les effets du vêtement sur les réactions isothermes, la fatigue perçue et le confort isotherme. Les combinaisons de surf traditionnelles sont conçues pour une isolation isotherme sans tenir compte des groupes de muscles qui génèrent le plus de chaleur. Salomon évaluera les propriétés isothermes afin de concevoir des combinaisons de surf futures ayant différentes isolations selon l'accumulation thermique des activités de surfing. Toutes les combinaisons ont été confectionnées à partir de panneaux similaires en néoprène constitués de tricots synthétiques liés à un support en mousse mesurant de 2,5 millimètres à 3,5 millimètres d'épaisseur. Les principales différences entre les combinaisons se situent au chapitre du tissu contre la peau et de la quantité d'isolation du néoprène. Une première combinaison de surf possédait un tricot synthétique ordinaire avec 3,0 millimètres de néoprène , une deuxième comportait un tricot interne à velours pouvant servir à augmenter la quantité d'eau constituant la couche limite en vue d'augmenter l'isolation de la combinaisons sans augmenter l'encombrement de cette dernière et une troisième comprenait des panneaux additionnels en néoprène couvrant la partie supérieure de la jambe, la partie supérieure du torse et les bras, enfilés sous la première combinaison. Toutes les combinaisons ont été élaborées par Salomon afin d'offrir une isolation isotherme comparable, mais les prototypes des panneaux en néoprène utilisés comme partie de la troisième combinaison ont été conçus par les auteurs afin d'augmenter l'isolation appliquée directement sur les groupes de muscles actifs ou les régions les plus irriguées de sang. Quatre sujets mâles ont participé à l'étude en portant chacun les trois combinaisons dans de l'eau à des températures de 13 °C et 18 °C alors qu'ils étaient exposés à 120 minutes d'activité dont 72 minutes passées à ramer avec les bras en position couchée sur une planche de surf, 24 minutes à nager sur place et 24 minutes en position de repos immergée. Lorsque le sujet ramait avec les bras, son énergie métabolique correspondait en moyenne à 5,64 les valeurs au repos. Les sujets ont déterminé que l'ajustement de la combinaison de surf et le mouvement de l'eau à l'intérieur de la combinaison de surf étaient des facteurs de confort importants. L'accumulation de sueur n'a jamais été un problème. La combinaison présentant l'isolation non uniforme a obtenu les meilleures réactions physiologiques et les meilleures cotes de confort isotherme, mais elle a été perçue comme étant moins souple exigeant ainsi un effort accru des muscles deltoïdes médiaux et postérieurs. La combinaison à couche limite améliorée était la moins chaude surtout pour la partie inférieure de la jambe, mais le niveau de fatigue à l'effort perçu par les sujets était moins élevé en raison de la mince épaisseur du néoprène. La combinaison à isolation non uniforme est celle qui a présenté le plus grand confort isotherme dans les conditions d'essai. Les panneaux de néoprène additionnels portés sous la combinaison

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de surf expliquent cette préférence. L'isolation de la partie inférieure du corps de toutes les combinaisons doit être maintenue afin d'assurer le confort isotherme. Si une combinaison doit être choisie en termes de confort et de protection dans les conditions soumises à l'essai, la combinaison non uniforme serait privilégiée.

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This trial would have been impossible without subjects willing to swim in cool water for hours. Due recognition is awarded to those who gave strenuous efforts for our study. DCIEM's Experimental Dive Unit members were gracious to lend their static water pool while their engineer, Martin Necpal, was kind to adjust water volume and temperature. Scientific help came from DCIEM's Human Performance and Protection group. Jan Pope was key to assessing subjects' arm ergometer work capacities and oxygen consumptions. Robert Limmer was essential in preparing most electronics including sensors, harnesses and data acquisition programs; the greatest help was his instructional, countdown surf timer program used by subjects to monitor their activity progression. Debbie Kerrigan-Brown was kind to monitor several sessions and prepare some temperature figures seen throughout this report. Easy work came from this calm group.

1. Introduction

Salomon expanded its scope of expertise by development of technical clothing for a variety of outdoor sports including surfing. The company approached DCIEM with three prototype surfsuits and agreed 13°C and 18°C water temperatures were suitable to test for thermal and subjective characteristics. All surfsuits were assembled from like panels of neoprene fabric consisting of synthetic tricots bonded to a foam core measuring 2.5 millimetres to 3.5 millimetres thick. The main differences between surfsuits were the fabrics against the skin and the amount of neoprene insulation. One surfsuit has normal synthetic tricots with 3.0 millimetre neoprene, while a second surfsuit had a piled inner tricot to possibly increase the amount of water comprising the boundary layer with the objective to increase the insulation of the suit without increasing suit bulkiness, while a third surfsuit had additional neoprene panels covering the upper legs, upper torso and arms yet worn beneath the first surfsuit. All surfsuits were developed by Salomon to provide comparable thermal insulation. The prototype neoprene panels worn as part of the third surfsuit were developed by the authors to increase the insulation directly over active muscle groups or areas of high blood flow. Care was taken to cut these panels to minimise interference with the active limbs' articulations thereby minimising an increase on surfing workload.

The main objective of the comparative study was to test the thermal characteristics of the surfsuit prototypes during simulated surf activity in 13°C and 18°C water temperatures, and to evaluate the clothing effects on thermal responses, perceived exertion and thermal comfort.

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2. Methods

2.1 Subjects

Four male subjects participated in the present experiment. Their physical characteristics are outlined in the Table 1. Subjects were asked to avoid alcohol, caffeine and intense exercise twenty-four hours before each experimental session. Subjects were verbally informed of the study after reading the approved protocol. Each subject voluntarily signed an informed consent form before participation. The protocol (L-320) was approved by the DCIEM Human Ethics Committee.

Table 1: Subject characteristics

Subject	Age (yr)	Height (cm)	Mass (kg)	Surface area (m^2)	VO_2 max. (l/min)	VO_2 max. (ml/kg/min)	Body fat (%)
1	41	183	85.11	2.07	2.52	29.6	18.4
2	30	176	78.90	1.95	2.91	36.9	13.2
3	30	177	81.45	1.99	2.94	36.1	15.5
4	23	181	72.99	1.93	2.68	36.7	13.5
average	31	179.3	79.61	1.99	2.76	34.8	15.2
sd	±7.4	±3.3	±5.1	±0.1	±0.2	±3.5	±2.4

2.2 Preliminary test

A physician medically screened each subject before their participation was accepted. Each subject performed a maximal aerobic power test (VO_2 maximum test) on a seated arm crank ergometer. Initial resistance was sixty watts for a five minute warm up with eighteen watt or thirty watt (Subject 4) increases every three minutes thereafter. Four to seven increases were required before subjects were exhausted and unable to maintain minimum cadence. Arm crank cadence of sixty revolutions per minute was expressed with a visible and an audible metronome. The test was used to extrapolate each subjects paddling intensity (VO_2) from their heart rates recorded during experimental sessions. During prone arm paddling subjects were expected to reach and maintain a workload of sixty-five percent of their arm crank ergometer maximal aerobic power test. Percent body fat was estimated from five skin-fold measurements (triceps, subscapularis, suprailiac, abdominals and quadriceps) using a skin fold calliper (John Bull British Indicators, Great Britain) with the Plyley, Shephard and Forsyth formula (1). Body surface area was estimated with the Dubois and Dubois formula (2).

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2.3 Procedures

Subjects were tested between August and December 2001. Each experiment session was 120 minutes of simulated surfing activity preceded by two minutes of floating rest. Sessions required three and a half hours to weigh items, apply instruments, dress, perform simulated surf activities, undress, remove instruments and reweigh items. Subjects were assigned to either morning or afternoon sessions based upon their preference. Subjects were tested at the same time of the day for each condition. Subjects wore each of three surfsuits in each of two water temperatures for a total of six experimental conditions. Salomon provided the three surfsuits. The authors designed and provided the non-uniform insulation panels. Each subject provided his own underwear briefs, which were the same short style between subjects.

Subjects were first instructed on proper hygienic handling and care of their rectal probe (YSI Incorporated, Yellow Springs, Ohio) then given their probe to insert fifteen centimetres into their rectum. When the probe was inserted and the subject was ready, their rectal temperature was recorded with a handheld digital reader (Doric Instruments, San Diego, California). During probe insertion or removal periods the experimenter was in the next room whereas a physician was on-call in the building during the entire experimental session.

Subjects arrived at the scale area where their individual nude mass was measured while they stood quietly on a floor scale behind a privacy curtain. Subjects dressed in their underwear briefs before meeting at the instrument dressing area. Each heat flux transducer skin site was cleaned with Reddi-Prep Alcohol Swabs (Ingram & Bell Medical, Don Mills, Ontario) and Skin Prep Protective Dressing Wipes (Smith & Nephew, Largo, Florida). A heat flux transducer was taped with Transpore Tape (3M Canada, London, Ontario) to each of forehead, chest, abdomen, neck, upper back, lower back, upper arm, lower arm, anterior thigh, posterior thigh, posterior knee and posterior lower leg. If a predominant muscle group was immediately near the site, attention was made to locate the sensor on the muscular group. A Polar Vantage NV (Polar Electro Incorporated, Port Washington, New York) chest strap heart rate transmitter was placed around the subject's chest. The rectal temperature probe was connected to the heat flow wiring harness. The experimenter then assisted dressing the subject into the surfsuit.

Heat flow transducer wires were spread and routed across and up the back against the skin to the overlap V at the rear of the inner neck seal. Each half of the overlap V was taped to its opposite panel and the rear of the inner neck seal collar with Duct Tape (3M Canada, London, Ontario) to prevent the ten millimetre diameter wire cluster from affecting the inner collar's waterproofness. The wiring harness was passed through the outer neck seal opening before the seal perimeter was pulled over the head and attached to the mid-sternum closure. The external suit sensor wiring harness was connected to the heat flow wiring harness. Both the instrumented arm and leg were covered with Se Pro Net (Acme Healthcare, Arden, North Carolina) to prevent wire damage and inadvertent tape removal. The arm elastic tube net was taped at the left

shoulder of the outer neck seal and the lower forearm. The leg elastic tube net was taped at the upper thigh and the lower leg. The tubular elastic net was cut away from the elbow and the knee joint areas to restore normal movement. The Polar Vantage NV wristwatch heart rate recorder was then attached to the left wrist. A second heart rate wristwatch was taped to the right shoulder of the outer neck seal so the large-number display faced the experimenter during the experimental session.

Subjects walked ten metres from the instrumentation room to the swim pool. A twelve millimetre-wide safety harness was placed around the subject's shoulder circumference and connected from the shoulder blade area to the overhead beam crane with parachute shock cord. At stretched length, this high-test cord permitted the subject to perform all experimental activities and the experimenter to raise the subject's upper torso from the water level if needed. The wiring harness was connected to the overhead ribbon wire, which connected all sensors to the data acquisition system. These wire-to-wire connectors were wrapped with Transpore Tape to improve waterproofness. Subjects participated with the author from this time through the surf activity until the session was complete. A subject never requested withdrawal from any session.

The 120 minutes of simulated surf activity included prone arm paddling, supported immersed rest and immersed treading water. These activities were chosen to duplicate the thermal exposure and workload of surfing. Ten-minute activity cycles began with five minutes of arm paddling, two minutes of rest, one minute of arm paddling and two minutes of treading water. The five minutes of arm paddling simulated the arm work required to get through incoming waves to an offshore wave waiting area. The two minutes of partially immersed rest kept the torso at the same water level as if the subject were sitting on their surfboard while waiting for an appropriate wave to ride inshore. The one minute of arm paddling duplicated efforts required to chase and catch a wave. The two minutes of treading water simulated the fall off the finished wave and the surfsuit flooding through its neck and cuff seals. This treading water phase also duplicated the worst-case-scenario when a surfer has lost their surfboard or they cannot stay upon their board due to ability or sea conditions.

A computer program was developed and displayed to inform the subject when they were to change between activities. This program was run and displayed on a laptop screen; it boldly displayed the present activity, the time remaining in the present activity, the time passed in the present activity and the total time elapsed. Experimental sessions began with two minutes standing at poolside that was immediately followed by two minutes of immersed floating upright in the pool water. This one-time float at the start of immersion and the twelve, ten-minute activity cycles equalled a total 122 minutes of expressed data.

Arm paddling required a smooth mount and large leg kick onto the tethered board and balancing chest-down upon the foam covered surfboard top. Overhand swimming arm movements in the front crawl style were maintained at a frequency between seven and eleven pairs of left and right arm movements every ten seconds. The paddling water

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level was across the upper leg and buttocks with the back, shoulders and upper arms generally remaining wet from splashed water. During immersed rest, the subject stood spread-legged on either of two parallel, foam-wrapped pipes positioned one metre underwater with the arms randomly circling the water for balance. The resting water level was maintained near mid torso. Treading water activity was upright and in place so the subject maintained water level at their neck by making horizontal bent-arm sweeps and moderate bent-leg kicks; most joint movement occurred at the shoulder and the hip. During every activity transition subjects submerged their head, neck and shoulders forward and below the water level for two seconds to simulate oncoming waves that would normally require the surfer to duck themselves and their board into and under the approaching wave.

An empty urine bottle and a Gatorade-filled (Quaker Oats Company of Canada, Peterborough, Ontario) bottle were kept at poolside within the subject's reach during standing rest. Each subject consumed a minimum 300 millilitre volume of Gatorade throughout the immersed rest periods of the first sixty minutes, thereafter, the subject was free to drink as desired. This fluid intake was estimated to replace most of the sweat produced from the experimental activities. The masses of each volume generated or consumed were measured. An experimental session from two different conditions was interrupted for urine collection. The first was paused at 98 minutes of the N surfsuit condition in 13°C water while the second was stopped at 109 minutes of the NU surfsuit condition in 18°C water.

Water temperature was controlled to either 13°C or 18°C with surface level re-circulation of tank water. The pool measured 2.53 metres by 2.53 metres across the surface and 2.70 metres deep; it was filled with 17000 litres of fresh water. Wind velocity was 20 kilometres per hour (5.6 metres per seconds) and directed lengthwise along the surfboard and slightly down onto the subject. Ambient air temperature was measured 1.00 metre above the water level at the pool edge. Ambient water temperature was measured 1.00 metre below the water level and 0.10 metres from the pool wall. During paddling activity, sharp waves averaged 0.25 metres from trough to tip.

The surfboard was chosen to fit within the left half of the pool surface area leaving the right half for immersed rest and treading water. The surfboard measured 1.981 metres long, 0.289 metres wide 0.305 metres from the tip, 0.343 metres wide 0.305 metres from the tail and 0.473 metres wide with 0.060 metre thickness at mid-length. The surfboard measurement descriptor is 78, 11 3/8, 13 4/8, 18 5/8 and 2 3/8 – surfboards are measured in imperial units and described in this precise manner. Specially designed nylon-webbing straps were wrapped around the mid-tip and mid-tail but connected together underneath with lengthwise portions of adjustable webbing lengths. Three non-stretch lines were tied to the surfboard. One line at the mid-tip connected the bottom centre of the board forward to the pool wall. Two lines at the sides of the mid-tail strap connected the bottom sides rearward to the pool wall at a forty-five degree angle from each other. During arm paddling activity this tethered surfboard tended to sink more than when arm paddling untethered. A 9.379 litre piece of

expanded polystyrene which measured 1.218 metres long by 0.220 metres wide by 0.035 metres thick was tied beneath the surfboard to duplicate a larger surfboard's buoyancy. The experimental surfboard was not free to plane naturally during forward paddling activity as it was tethered to one metre of movement in either plane.

Laminated pages that displayed the perceived exertion and thermal comfort scales were attached to the surfboard and the pool wall forward of the surfboard. Subjects rated both scales after each five-minute paddling session. Subjects were permitted to adjust, or request an experimenter's aid in adjustment of, the surfsuit openings or seals but never did. Subjects did stretch during rest activity.

2.4 Clothing

The tested surfsuits were cut from different neoprene materials consisting of inner and outer tricot fabrics glued to a neoprene foam core – the resulting laminate is known as neoprene regardless of the individual component characteristics. Between surfsuits, outer fabric and shape of each surfsuit panel were the same while inner fabric and foam core thickness were different. The outer fabric was synthetic tricot with a chemical water repellency treatment.

The standard normal surfsuit (N) was cut from 3.0 millimetre neoprene with plain inner tricot similar to the standard outer tricot. The enhanced boundary surfsuit (EB) was cut from 2.5 millimetre, 3.0 millimetre and 3.5 millimetre neoprene panels with standard and enhanced inner fabrics. The enhanced inner surface was either <0.5 millimetres or 1.0 millimetre of stiff upright looped threads woven from the base tricot. Lightly compressed, these pile fabrics were 3.5 millimetres thick of which at least 3.0 millimetres was neoprene foam core. The enhanced fabric could create a thicker water boundary layer against the skin. Several inner leg and arm panels were 2.5 millimetre neoprene to improve limb movement, improve panel stretch or decrease insulation. Low pile inner tricot was incorporated into upper outer arms, shoulders, shoulder blades and down to the lateral low-rib regions. Normal inner tricot was incorporated from the low-rib regions down the lateral leg to the knee covering both the anterior and posterior thigh skin sensors and five centimetres to fifteen centimetres of the neck seal; these neoprene panels were also 2.5 millimetres thick. The non-uniform surfsuit (NU) was a multi-piece ensemble that consisted of five neoprene panels worn underneath N. The upper torso, upper legs and arms were covered with fitted panels of 3.0 millimetre neoprene with a surface area totalling 0.395 square metres. Eighty-six percent of the average subject surface area was covered by all surfsuits of which twenty-three percent was double insulated in NU. The neoprene panels used with NU were developed by the authors to optimize thermal comfort and muscle performance during surf activity in cold water.

Positive buoyancy was recorded as the underwater mass of each surfsuit when placed upon an underwater scale platform with an object of known mass to hold the surfsuit underwater. This mass value changed among surfsuits due to the amount of gas trapped within the panels' foam cores and two fabric tricots. Positive buoyancy was

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measured as the difference between the underwater harness mass and the harness with each surfsuit. N weighed 1170 grams with 2370 grams of positive buoyancy. EB weighed 1145 grams with 2520 grams of positive buoyancy. NU weighed 1920 grams with 3845 grams of positive buoyancy.

2.5 Measured parameters

2.5.1 Rectal temperature

Rectal temperature was measured with a thermistor (YSI Incorporated, Yellow Springs, Ohio) inserted fifteen centimetres into the rectum.

2.5.2 Heat flow and skin temperature

Heat flow and skin temperature were measured from twelve locations (see Table 2). Heat flow discs (Old Saybrook, Connecticut) were fixed to the skin with Transpore Tape (3M Canada, London, Ontario).

Mean body heat loss and mean body skin temperature were calculated based on a modified Hardy and Dubois weighting factor system average of twelve sites (3).

Table 2: Mean skin temperature and body heat flow weighting coefficients

Sensor location	Weighting factor
Forehead	0.070
Neck	0.044
Chest	0.088
Abdomen	0.088
Upper back	0.044
Lower back	0.088
Upper arm	0.095
Lower arm	0.095
Anterior thigh	0.095
Posterior thigh	0.095
Posterior knee	0.100
Lower posterior leg	0.100

2.5.3 External suit temperature

External suit temperature thermistors (YSI Incorporated, Yellow Springs, Ohio) measuring two by eight millimetres long were fixed with Duct Tape (3M Canada Incorporated, London, Ontario) to the surfsuit exterior corresponding to the skin-level heat flow sensors. As the forehead heat flow

sensor was not covered by the surfsuit, it was not instrumented for external suit temperature.

2.5.4 Heart rate

Heart rate was recorded each minute using a Polar Vantage NV heart rate monitor (Polar Electro Incorporated, Port Washington, New York) with the transmitter strapped around the chest and the wristwatch receiver and memory storage worn around the left wrist.

2.5.5 Metabolic rate

Each subject performed a maximal aerobic power (VO_2 maximum) test for arms on a seated arm crank ergometer. Initial resistance was set to sixty watts for a five minute warm up with eighteen watts or thirty watts (Subject 4) increases every three minutes thereafter. Four to seven increases were required before individual subjects became exhausted and unable to maintain minimum cadence. Arm crank cadence of sixty revolutions per minute was expressed with a visible and an audible metronome. Subjects breathed through a mouthpiece and hose attached to an air mixing-box where samples were analysed for percent of oxygen and carbon dioxide (AEI Technologies, Pittsburgh, Pennsylvania). Mixing box gases exited through a vane anemometer that recorded expired volume. Gas sensors were calibrated with sixteen percent oxygen and four percent carbon dioxide calibration gas (BOC Gases, Mississauga, Ontario). When steady state heart rate was reached during each of the exercise intensities, heart rate and corresponding stabilized oxygen consumption were recorded. Data were recorded and printed after each subject's assessment. Exercise stage heart rates and oxygen consumptions were plotted against each other for a linear regression of each subject's paddling intensity as a percent of VO_2 maximum.

2.5.6 Activity Level

Metabolic gas assessment was felt to be detrimental to subject safety during facedown arm paddling on a surfboard, therefore arm paddling activity level was monitored by heart rate. A heart rate representing sixty-five percent of the preliminary maximum aerobic power test value was chosen for each subject. Subjects were instructed to maintain their heart rate for each paddling effort without drastic changes to intensity nor cadence. Heart rate was visible to the subject on the wristwatch heart rate monitor display placed around their left wrist. Heart rate was visible to the experimenter on the wristwatch heart rate monitor display taped to the subjects right shoulder. Subjects performed seven to eleven pairs of arm strokes each ten seconds. Activity level was fine-tuned by instruction from the experimenter to increase or decrease paddling cadence. During most experimental conditions, a metabolic assessment was performed during an arm paddling session within

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the first thirty minutes of exposure. This metabolic assessment monitored nearly real-time arm paddling intensity as active heart rates alone were not guaranteed to be repeatable between experimental sessions. Great attention was taken to control arm paddling workload for each subject throughout their familiarisation and experimental exposures.

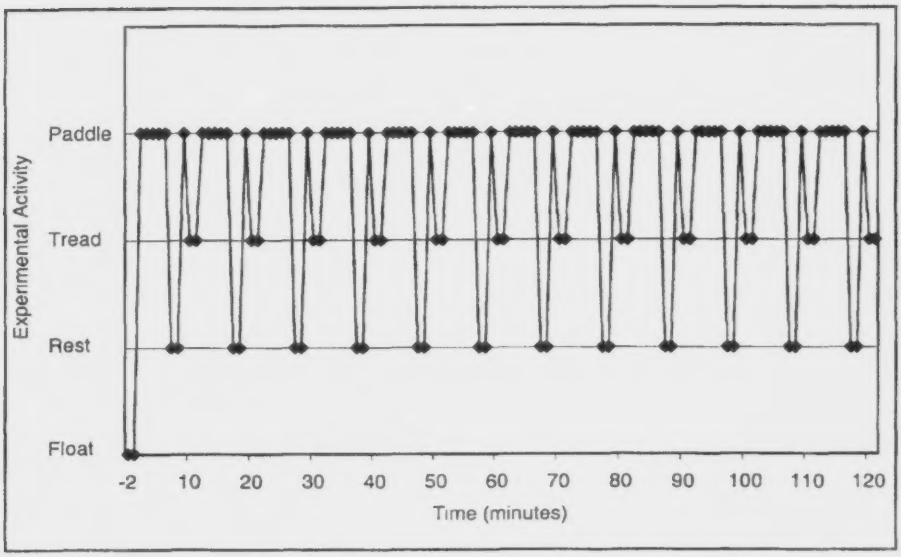

Figure 1: Experimental activity required of each subject for each experimental exposure.

2.5.7 Heat balance

Radiative, convective and conductive heat flows were measured using two millimetre thick by twenty-five millimetre diameter heat flux transducers with embedded thermistors (Concept Engineering, Old Saybrook, Connecticut). Mean body heat flow was calculated from subjects surface area divided by their weighted mean body heat flow.

2.5.8 Thermal comfort and perceived exertion

Thermal comfort and perceived exertion were rated by subjects before entering the water, after entering the water and after each five-minute arm paddling activity. The McGinnis thirteen-point Thermal Comfort scale (see Annexes) and the Borg fifteen point Perceived Exertion scale (see Annexes) were used. Two laminated pages which displayed both scales were attached to the surfboard and the pool wall forward of the surfboard.

2.5.9 Clothing insulation

Clothing insulation was calculated with this formula:

Insulation in Clo = (Weighted skin temp in °C – Weighted suit temp in °C) / Weighted heat flux in W/m^2) / 0.155

Heat flow and skin temperatures were measured from twelve locations (see Table 2) with heat flow discs (Concept Engineering, Old Saybrook, Connecticut) fixed to the skin with Transpore Tape (3M Canada, London, Ontario). External suit temperatures were measured with twelve, two millimetre by eight millimetre long thermistors (YSI Incorporated, Yellow Springs, Ohio) fixed with Duct Tape (3M Canada Incorporated, London, Ontario) to the surfsuit exterior corresponding to the skin-level heat flux sensors. Weighted values were calculated based on a modified Hardy and Dubois weighting factor system average of twelve sites (3).

2.6 Environmental conditions

Environmental conditions were maintained for all experimental conditions as described in the methods. Water temperature was controlled to either 13°C or 18°C with surface level re-circulation of tank water. Ambient water temperature was measured 1.00 metre below the water level and 0.10 metres from the pool wall. Ambient air temperature was measured 1.00 metre above the water level at the pool edge. These temperatures were measured with thermistors (YSI Incorporated, Yellow Springs, Ohio). Wind velocity was twenty kilometres per hour and directed lengthwise along the surfboard length and slightly down onto the subject.

2.7 Subject safety

Subject participation in any experimental session was terminated if an experimenter stopped an exposure or a subject requested withdrawal. No safety incidents arose.

2.8 Statistics

Statistical analysis was not performed, as the requested number of subjects was inadequate. This restriction was imposed by Salomon.

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3. Results

Values presented are averaged data originally collected every minute. Subjects experienced average exposures of one hundred and twenty minutes where seventy-two minutes were prone arm paddling, twenty-four minutes were treading water and twenty-four minutes were immersed rest. Standard deviations are expressed for histograms but time-related graphics would be illegible with standard deviations expressed.

3.1 Rectal temperature

Rectal temperature data are presented in Figures 2 to 5.

Average rectal temperatures were higher in 18°C water by an average of 0.2°C. No difference in core temperatures between suits in 18°C water. NU had highest rectal temperature by 0.4°C and 0.3°C in 13°C and 18°C water respectively. NU had the most consistent rectal temperatures. Subjects were slightly hypothermic after wearing N and EB in 13°C water.

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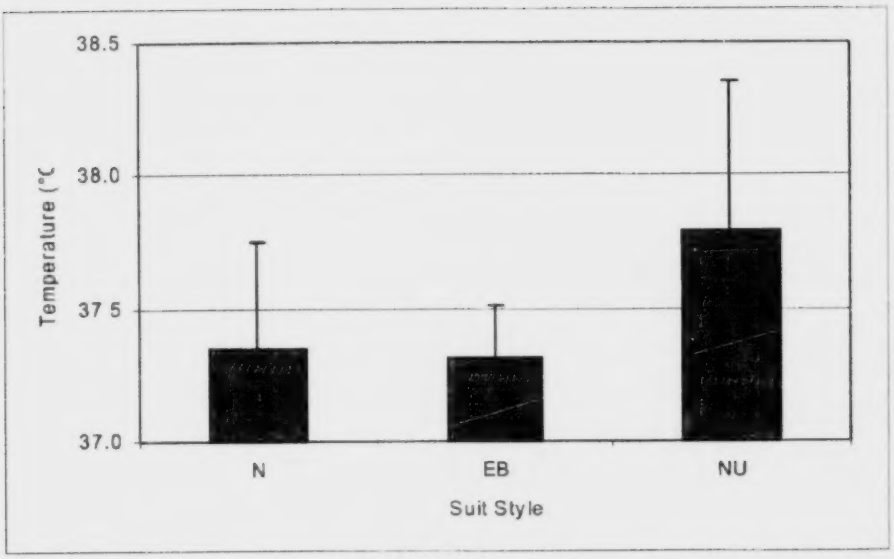

Figure 2: Mean rectal temperature of all subjects in 13°C water while wearing one of three surfsuits.

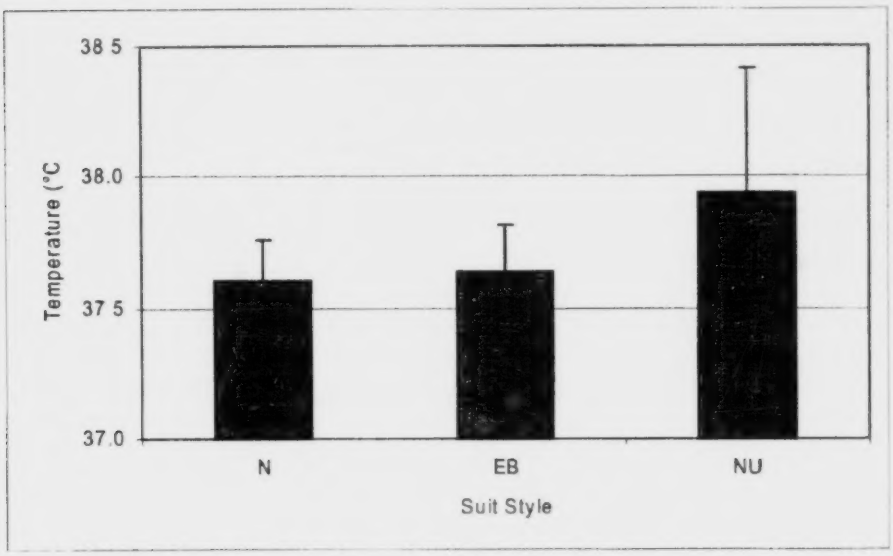

Figure 3: Mean rectal temperature of all subjects in 18°C water while wearing one of three surfsuits.

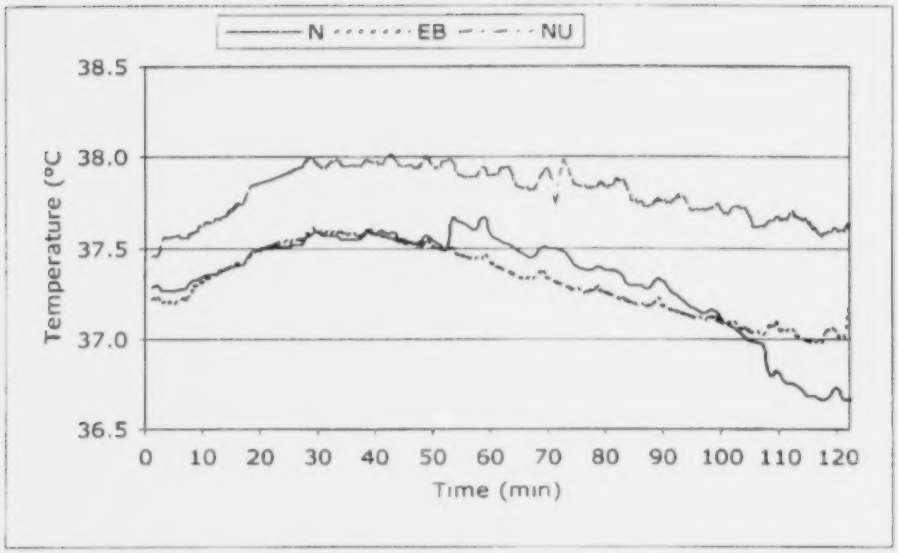

Figure 4: Mean rectal temperature over time of all subjects in 13°C water while wearing one of three surfsuits.

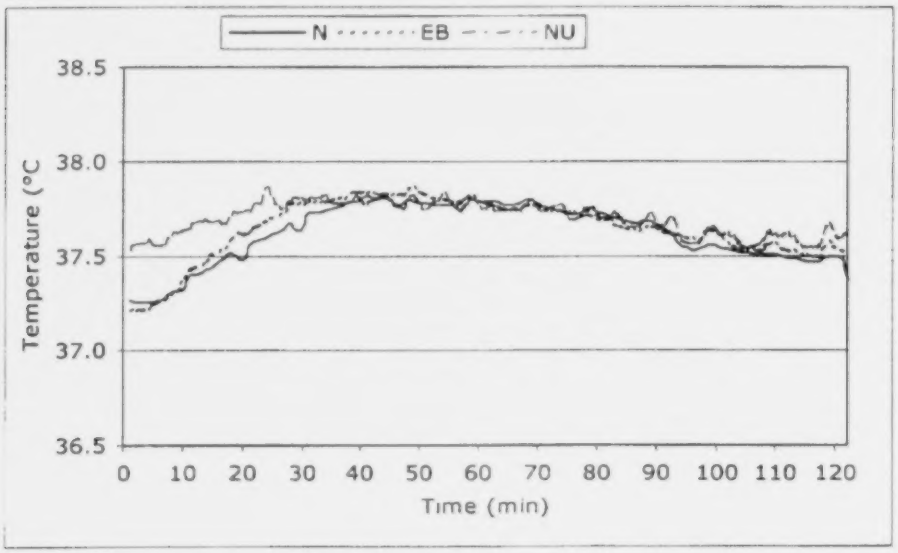

Figure 5: Mean rectal temperature over time of all subjects in 18°C water while wearing one of three surfsuits.

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3.2 Heat flow

Heat flow data are presented in Figures 6 to 17.

Heat flows were generally lower in 18°C water. Heat flows were higher for the upper torso and arm than the lower body. Average heat flux was about 30 to 50 watts per square metre lower for sensors under NU's additional insulation panels except for chest and forehead, which were either similar or greater than other surfsuit values in 18°C water. N may have a heat flow advantage over EB.

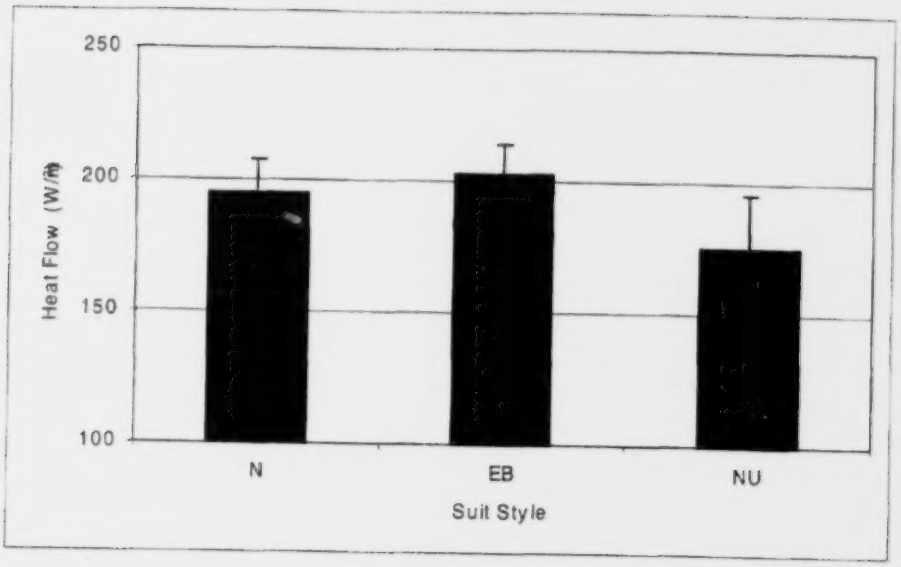

Figure 6: Mean heat flow of all subjects in 13°C water while wearing one of three surfsuits.

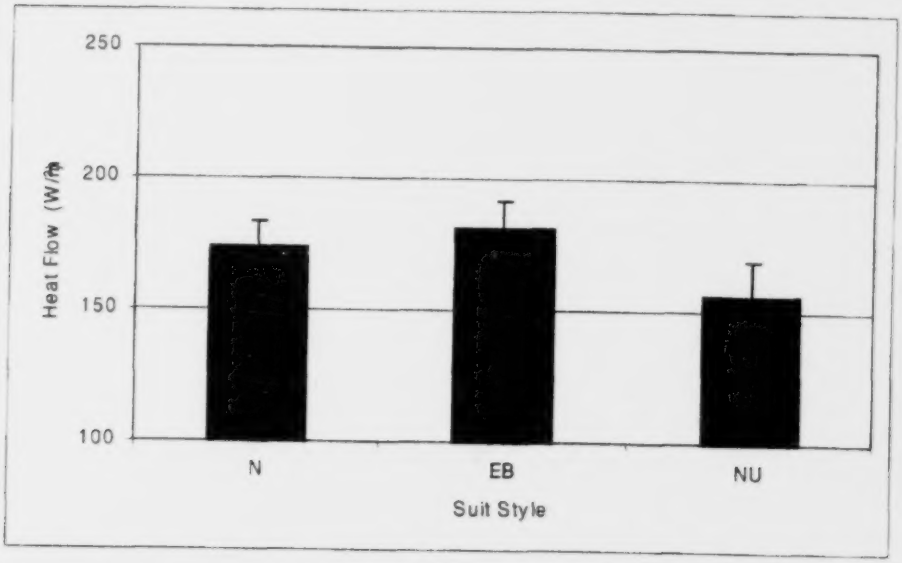

Figure 7: Mean heat flow of all subjects in 18°C water while wearing one of three surfsuits.

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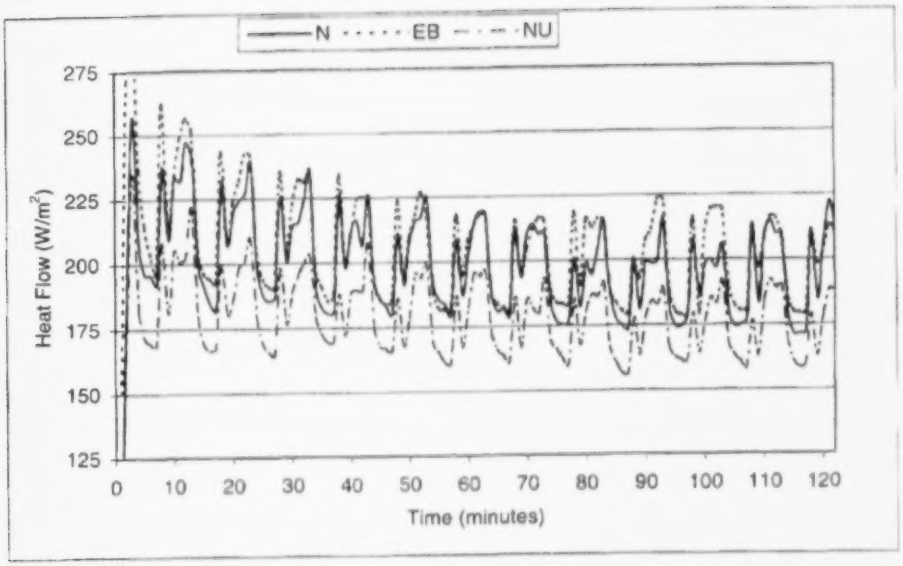

Figure 8: Mean heat flow over time of all subjects in 13°C water while wearing one of three surfsuits.

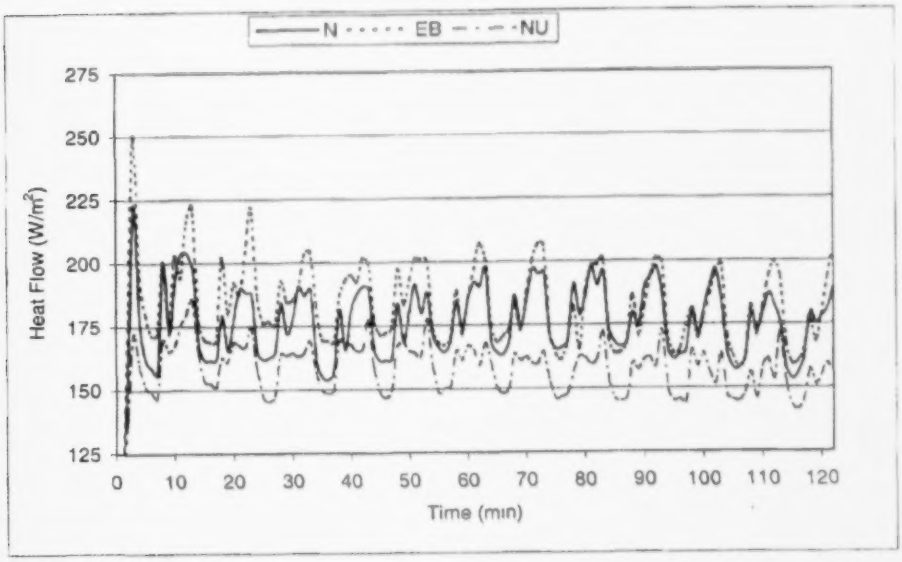

Figure 9: Mean heat flow over time of all subjects in 18°C water while wearing one of three surfsuits.

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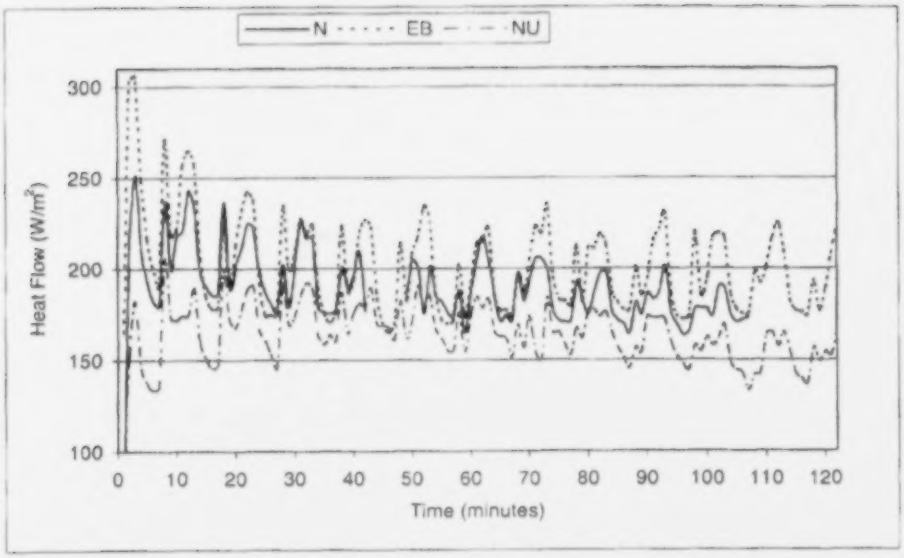

Figure 10: Mean heat flow over time for Subject 1 in 13°C water while wearing one of three surfsuits.

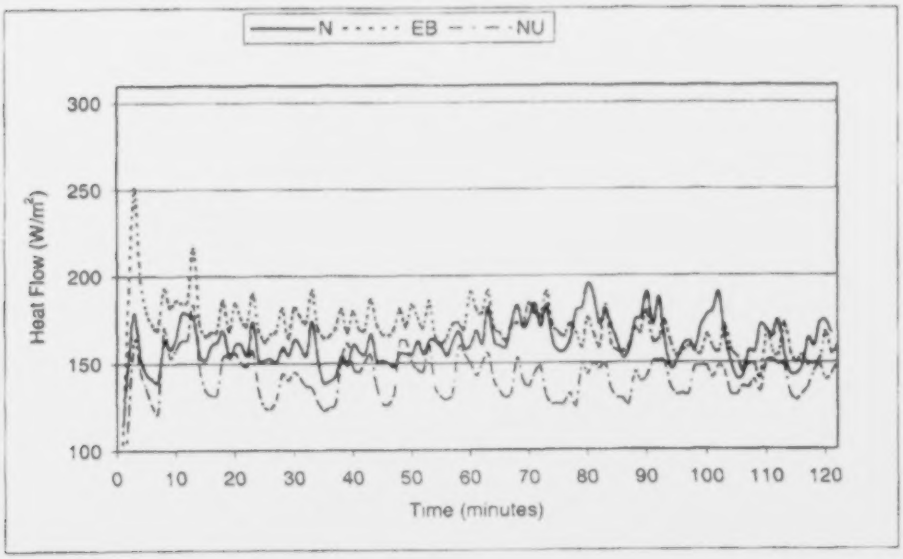

Figure 11: Mean heat flow over time for Subject 1 in 18°C water while wearing one of three surfsuits.

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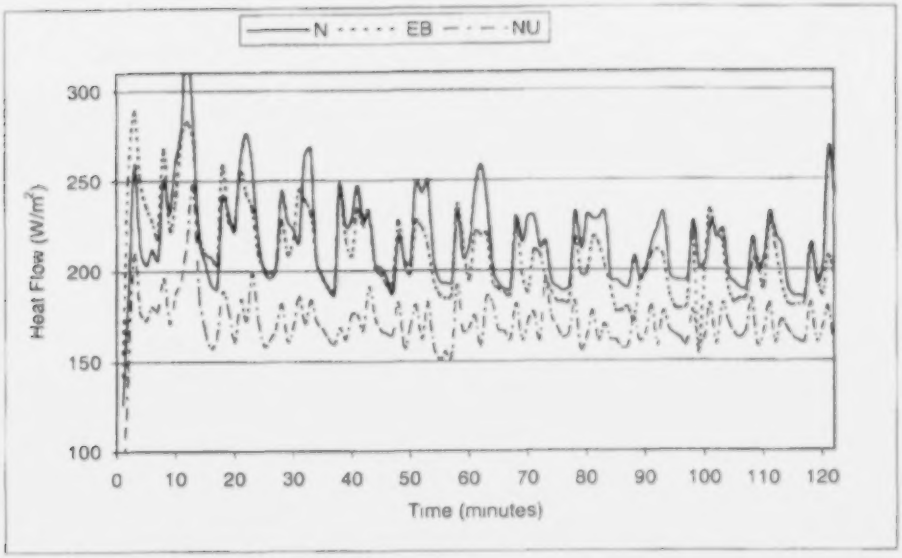

Figure 12: Mean heat flow over time for Subject 2 in 13°C water while wearing one of three surfsuits.

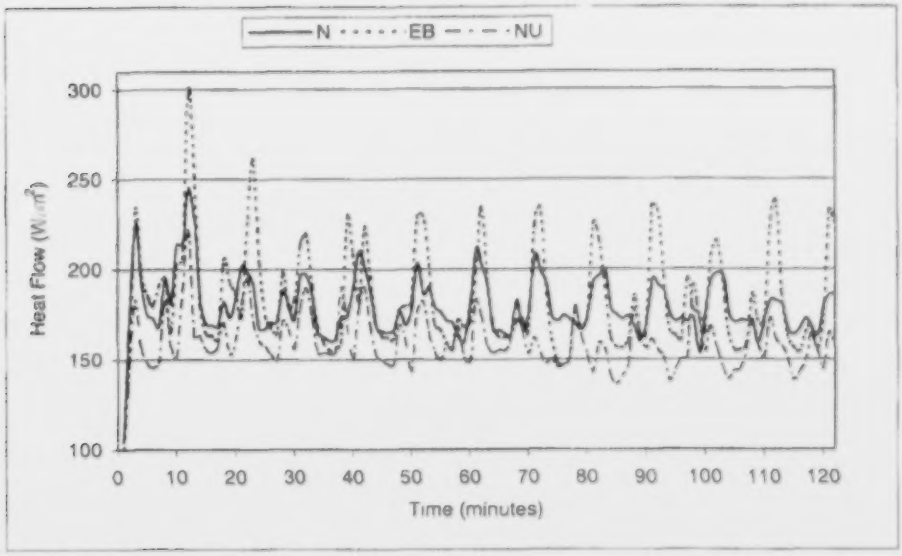

Figure 13: Mean heat flow over time for Subject 2 in 18°C water while wearing one of three surfsuits.

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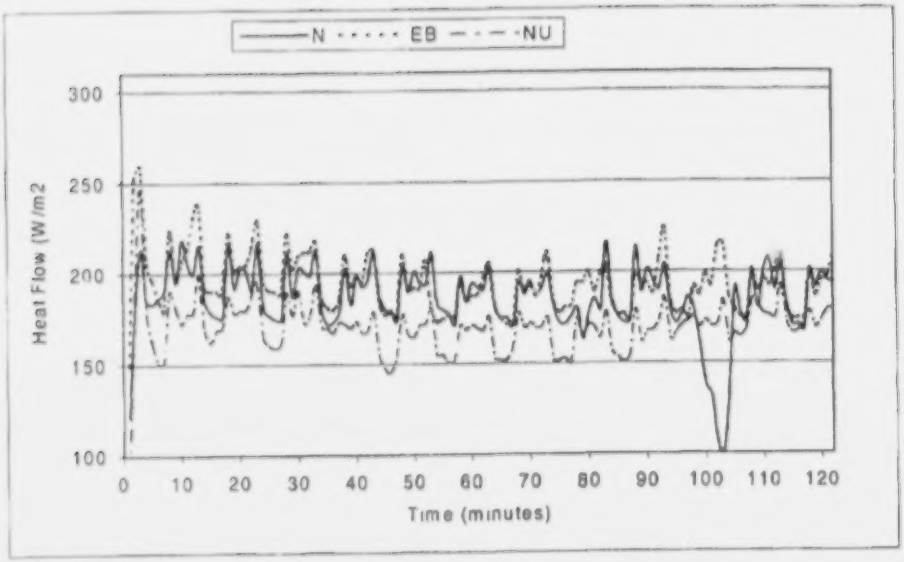

Figure 14: Mean heat flow over time for Subject 3 in 13°C water while wearing one of three surfsuits.

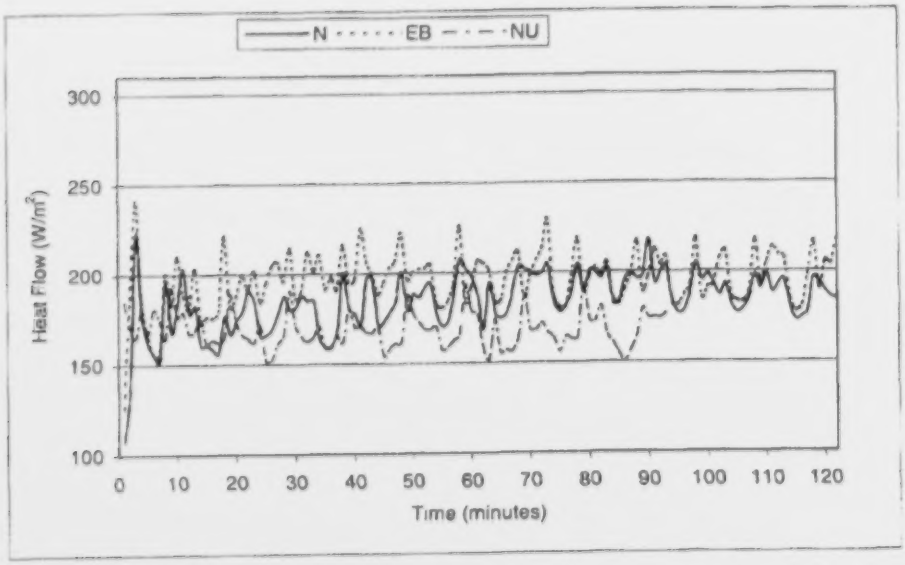

Figure 15: Mean heat flow over time for Subject 3 in 18°C water while wearing one of three surfsuits.

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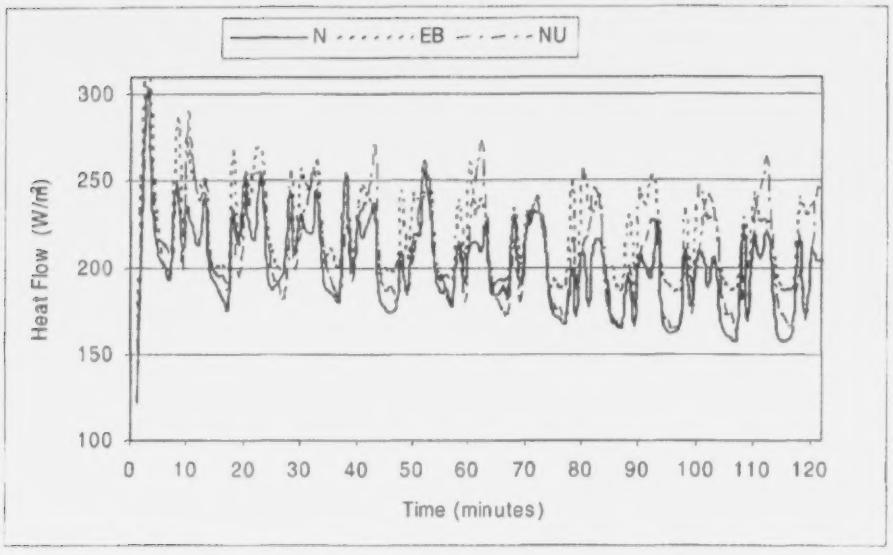

Figure 16: Mean heat flow over time for Subject 4 in 13°C water while wearing one of three surfsuits.

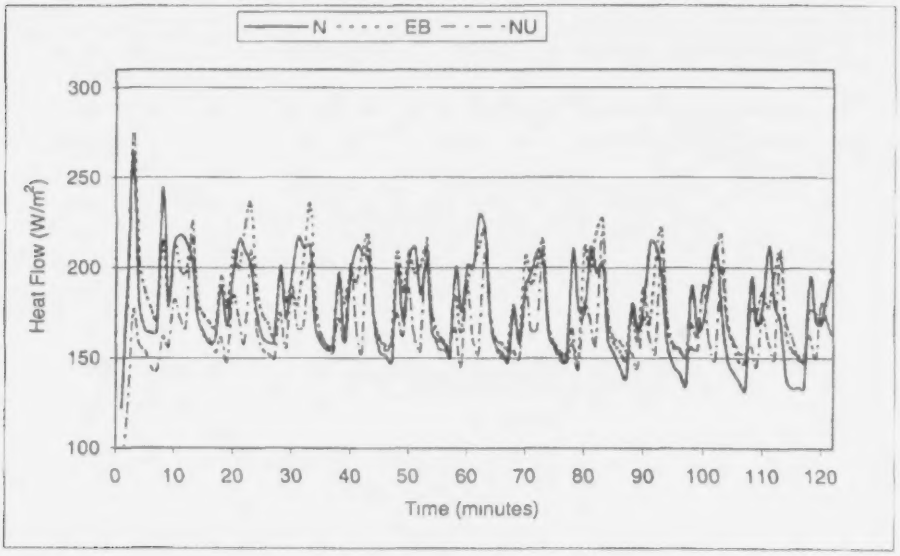

Figure 17: Mean heat flow over time for Subject 4 in 18°C water while wearing one of three surfsuits.

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3.3 Skin temperature

Skin temperature data are presented in Figures 18 to 29.

Skin temperatures were nearly 3°C lower in 13°C water. Skin temperatures were 2°C higher for NU for the double-insulated appendages and neck regions with torso values 1°C higher. N and EB were similar though EB legs were coolest of all surfsuits with posterior knee and posterior lower leg both 2°C cooler. Upper arm was coolest in N. Abdomen and low back were similar for all surfsuits.

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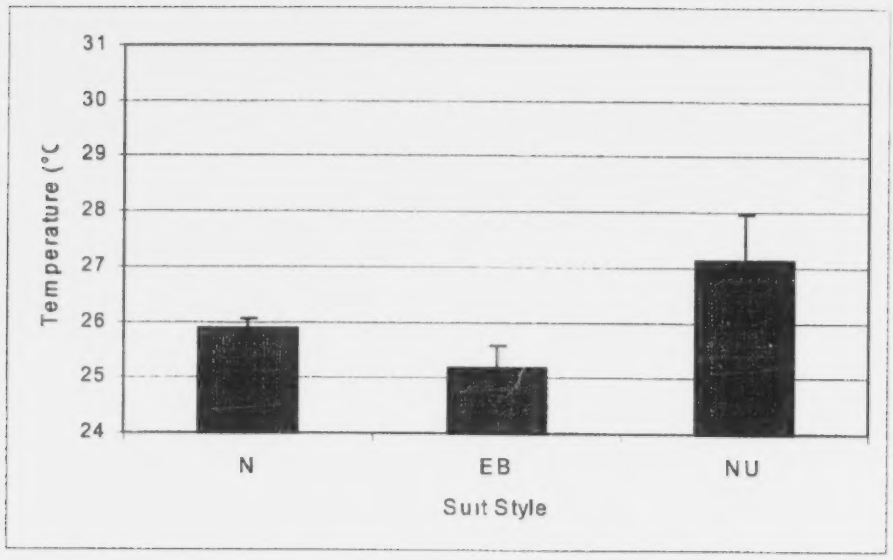

Figure 18: Mean skin temperature of all subjects in 13°C water while wearing one of three surfsuits.

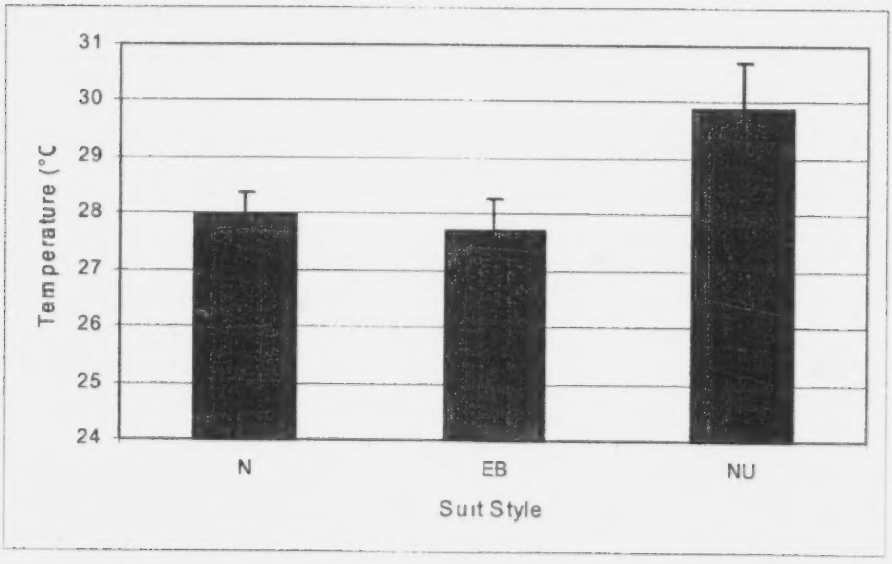

Figure 19: Mean skin temperature of all subjects in 18°C water while wearing one of three surfsuits.

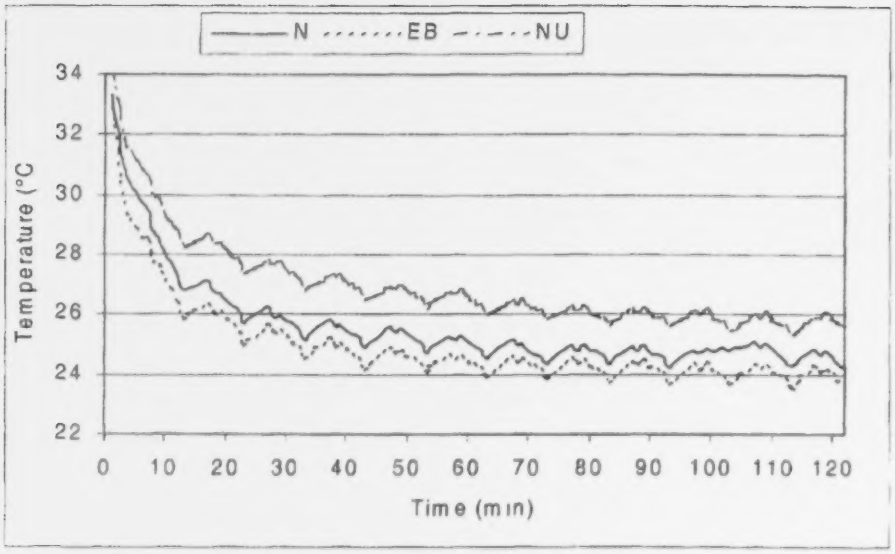

Figure 20: Mean skin temperature over time of all subjects in 13°C water while wearing one of three surfsuits.

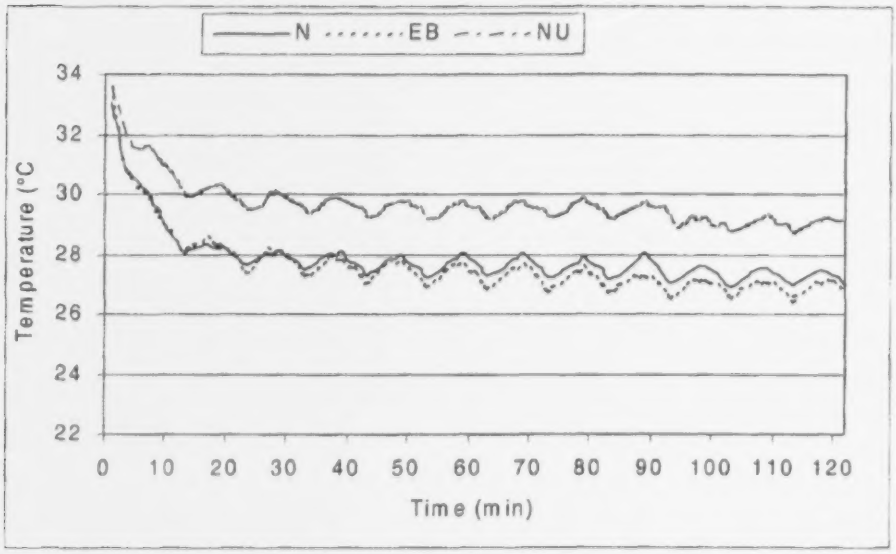

Figure 21: Mean skin temperature over time of all subjects in 18°C water while wearing one of three surfsuits.

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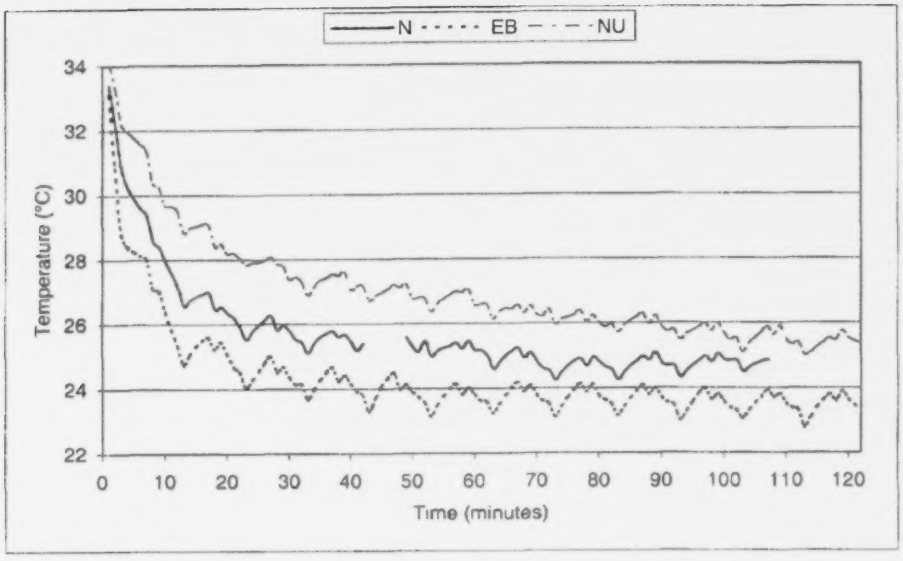

Figure 22: Mean skin temperature over time for Subject 1 in 13°C water while wearing one of three surfsuits.

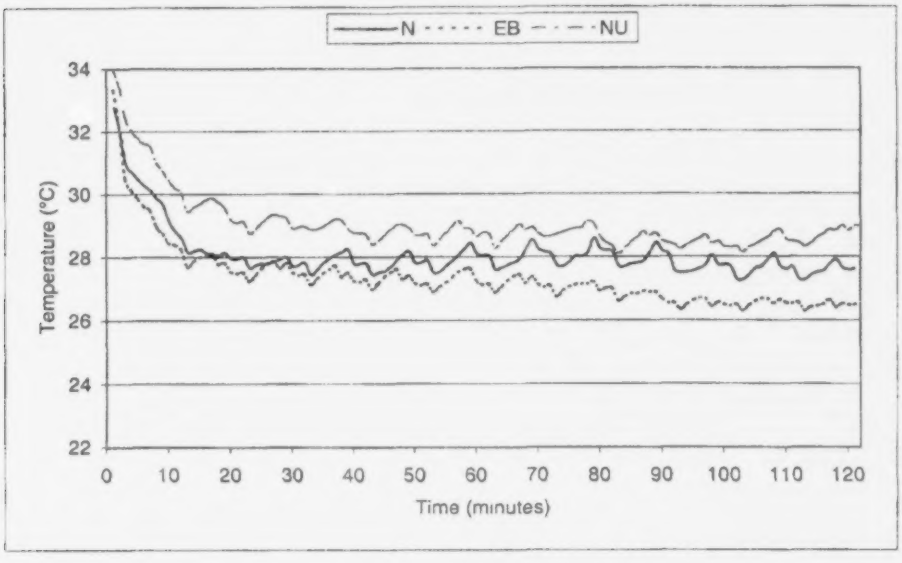

Figure 23: Mean skin temperature over time for Subject 1 in 18°C water while wearing one of three surfsuits.

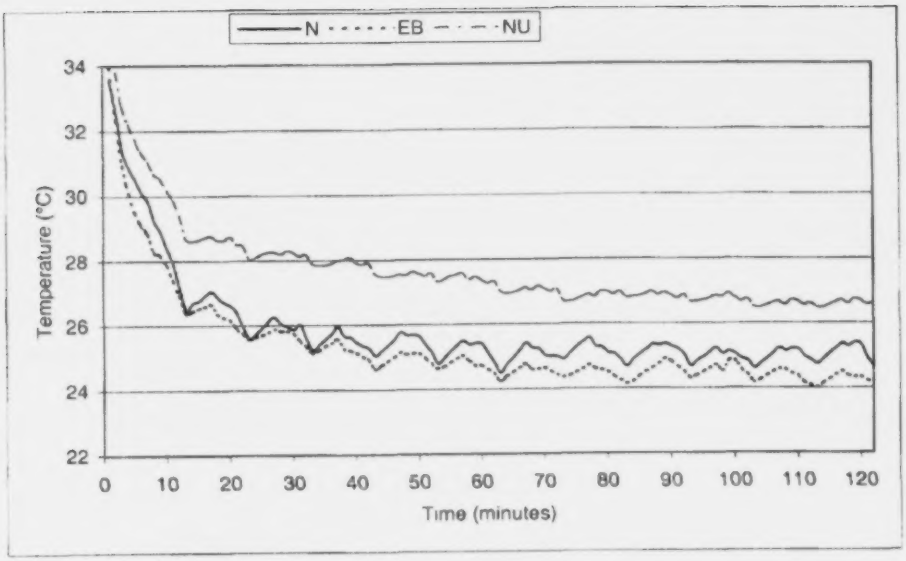

Figure 24: Mean skin temperature over time for Subject 2 in 13°C water while wearing one of three surfsuits.

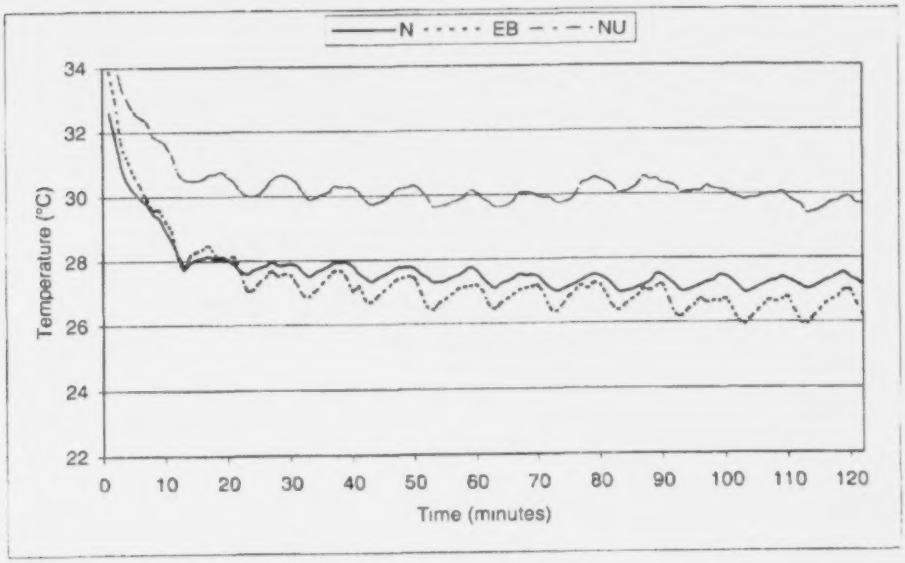

Figure 25: Mean skin temperature over time for Subject 2 in 18°C water while wearing one of three surfsuits.

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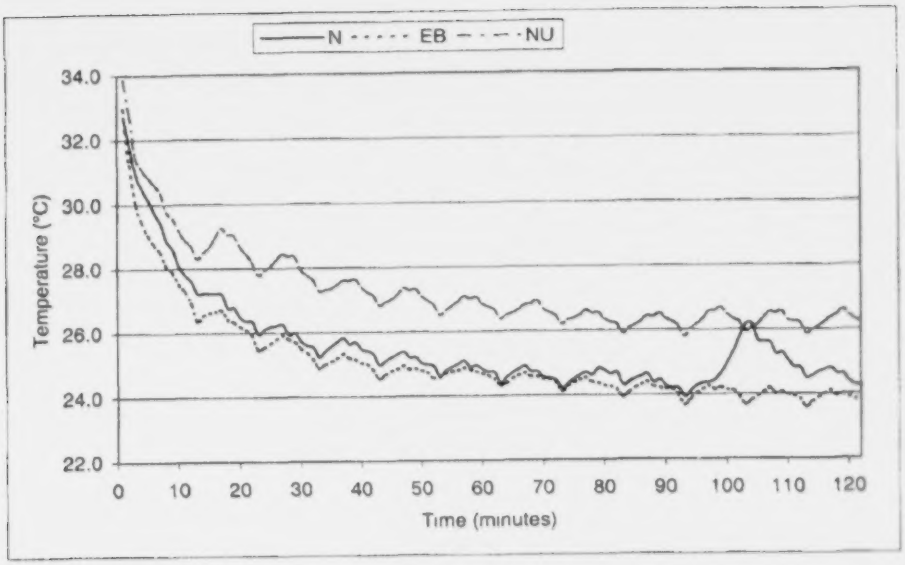

Figure 26: Mean skin temperature over time for Subject 3 in 13°C water while wearing one of three surfsuits.

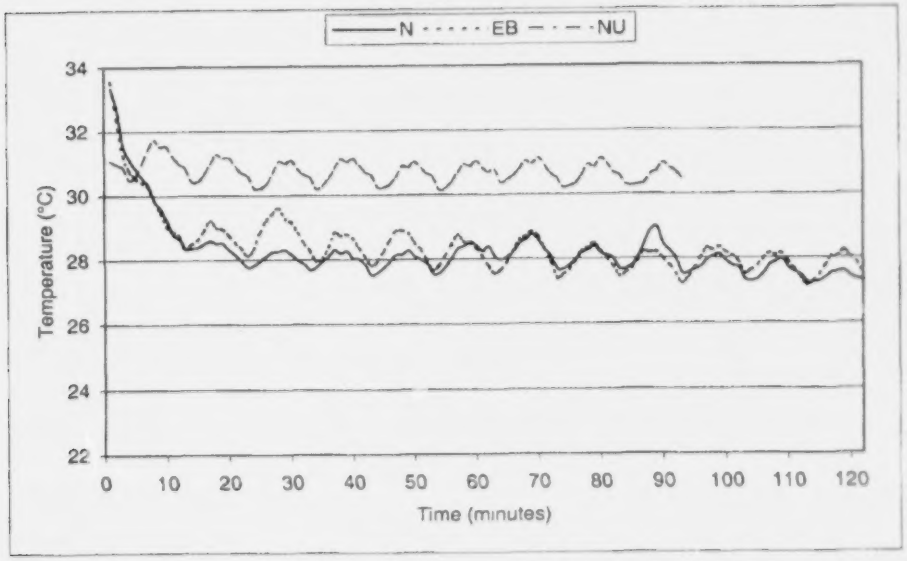

Figure 27: Mean skin temperature over time for Subject 3 in 18°C water while wearing one of three surfsuits.

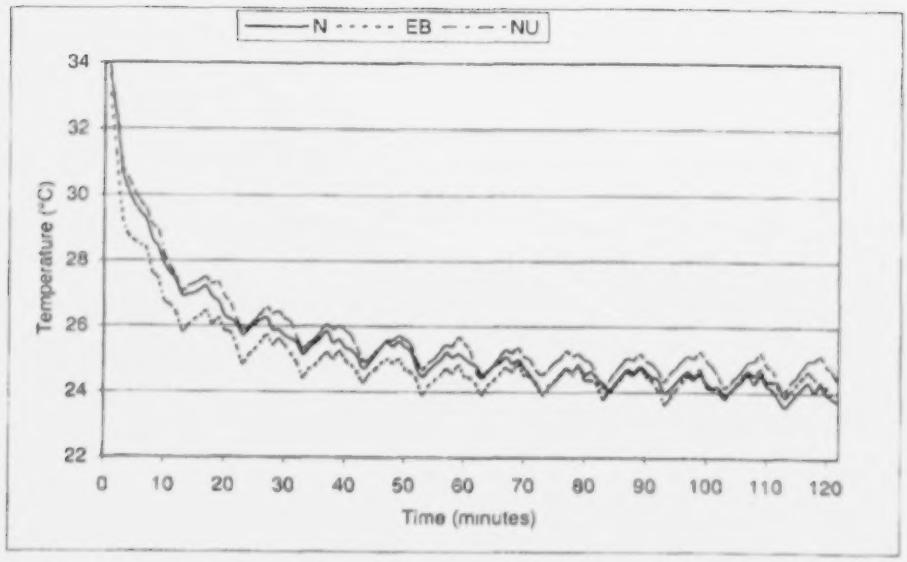

Figure 28: Mean skin temperature over time for Subject 4 in 13°C water while wearing one of three surfsuits.

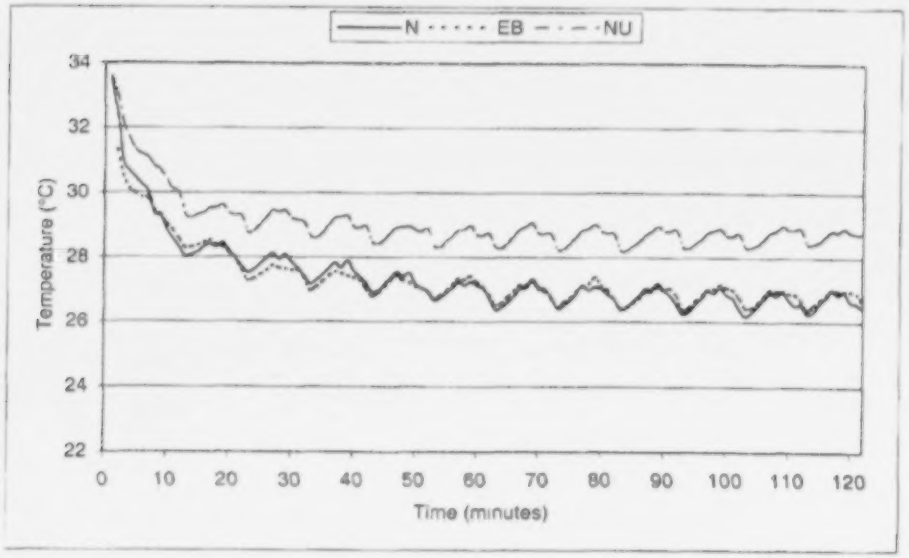

Figure 29: Mean skin temperature over time for Subject 4 in 18°C water while wearing one of three surfsuits.

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3.4 External suit temperature

External suit temperature data are presented in Figures 30 to 33.

Average external suit temperature was higher for N in 13°C water yet similar between other conditions respective to water temperature. EB was cooler in 18°C water.

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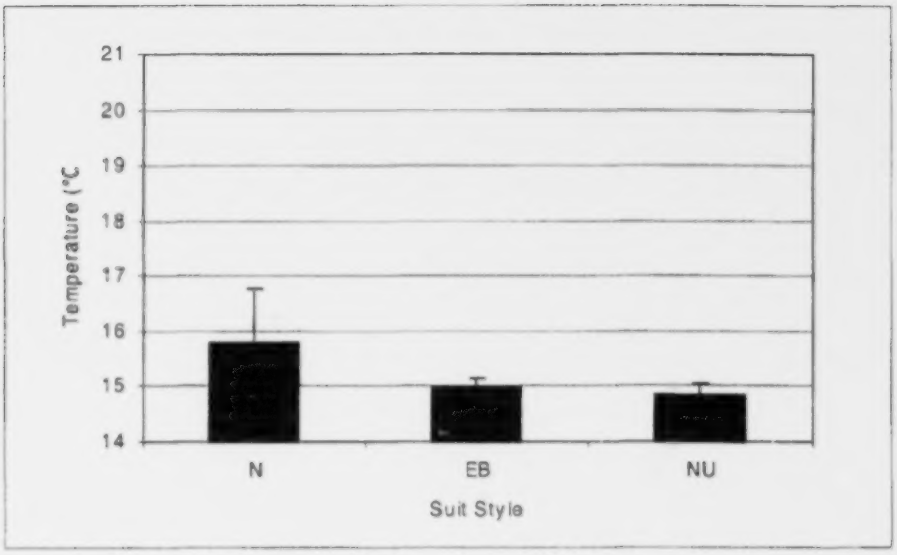

Figure 30: Mean suit temperature of all subjects in 13°C water while wearing one of three surfsuits.

Figure 31: Mean suit temperature of all subjects in 18°C water while wearing one of three surfsuits.

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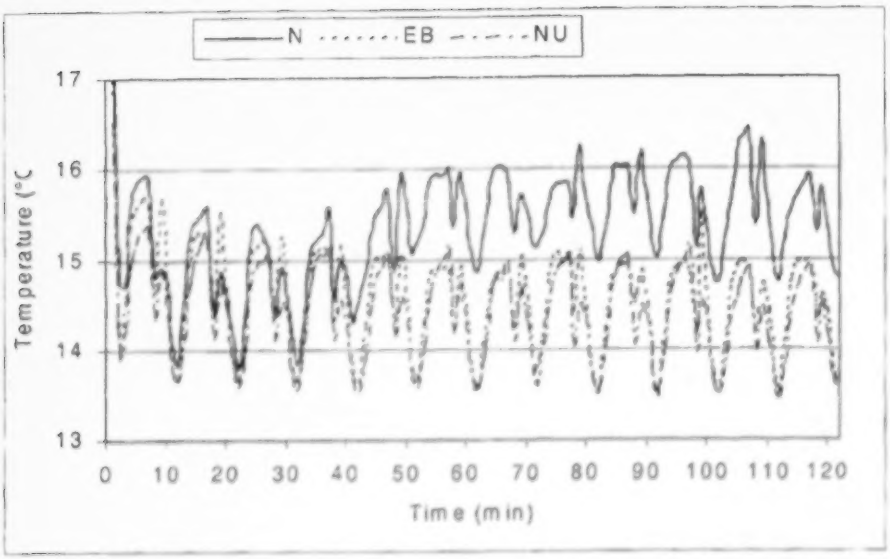

Figure 32: Mean suit temperature over time of all subjects in 13°C water while wearing one of three surfsuits.

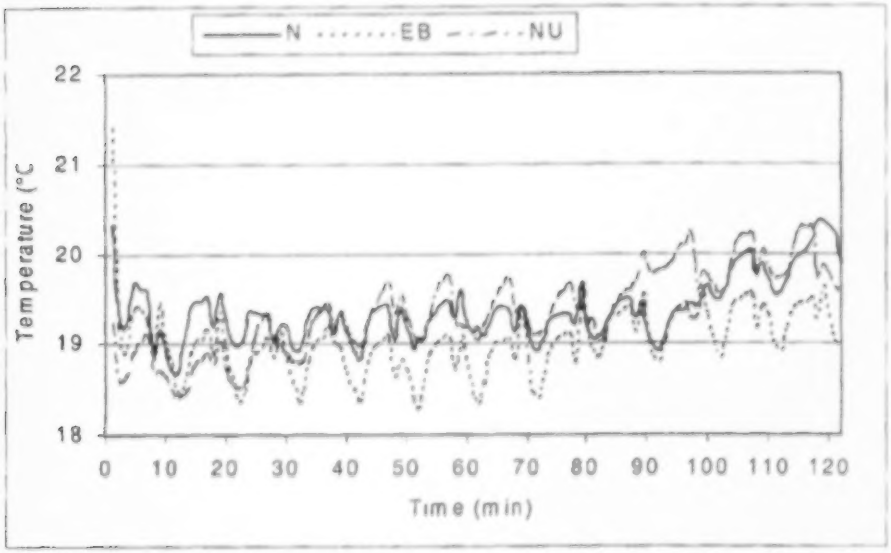

Figure 33: Mean suit temperature over time of all subjects in 18°C water while wearing one of three surfsuits.

3.5 Heart rate

Heart rate data are presented in Figures 34 to 37.

Heart rates were similar between conditions though generally higher in 13°C water. Heart rate average ranged between 125.9 and 128.4 beats per minute for all conditions. NU heart rates experienced the greatest range in 13°C water, and lowest values in 18°C water. NU heart rates were higher during the first and final arm paddling sessions regardless of water temperature.

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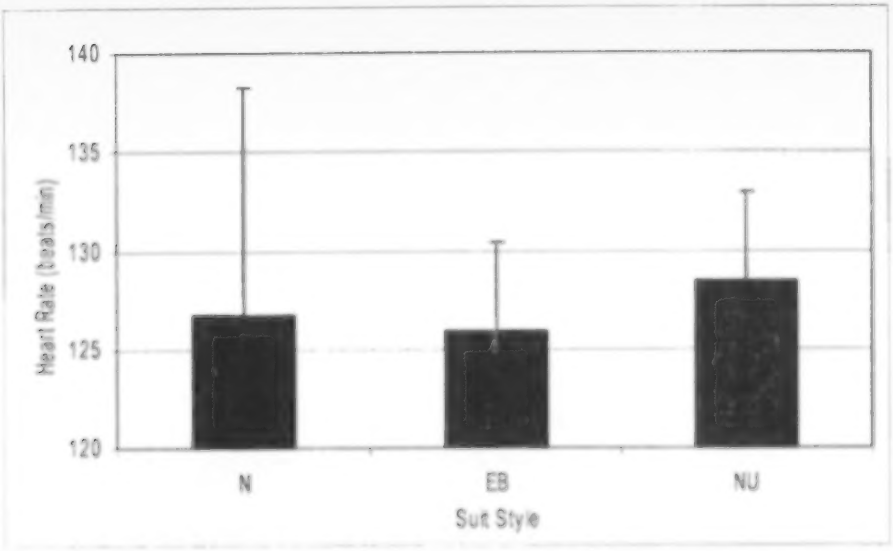

Figure 34: Average heart rate of all subjects in 13°C water while wearing one of three surfsuits.

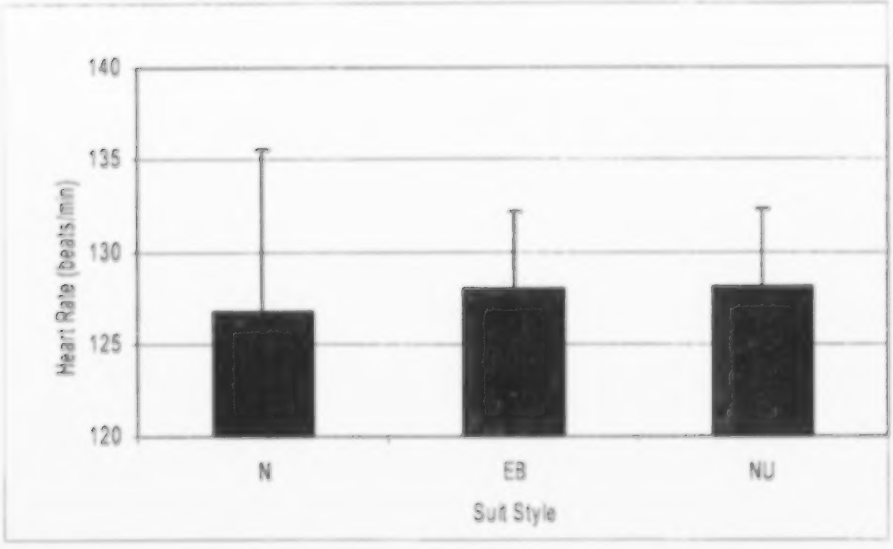

Figure 35: Average heart rate of all subjects in 18°C water while wearing one of three surfsuits.

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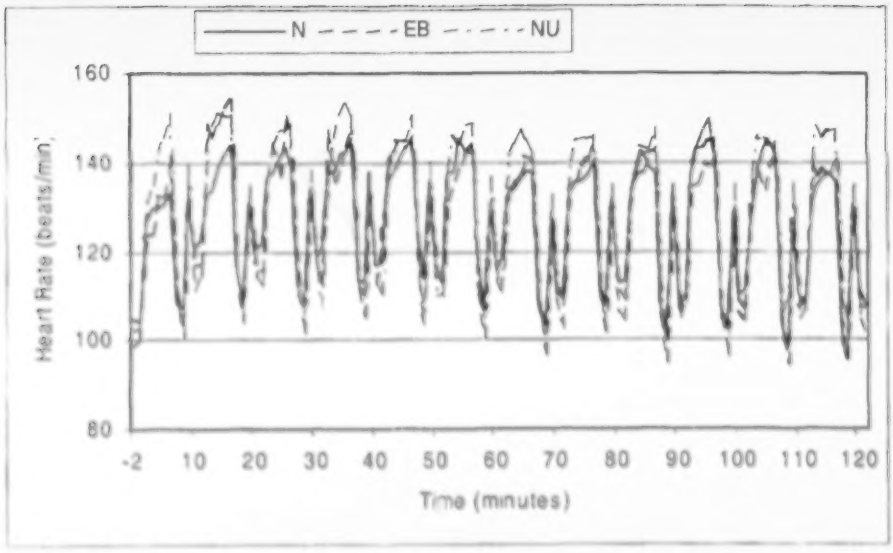

Figure 36: Average heart rate over time of all subjects in 13°C water while wearing one of three surfsuits.

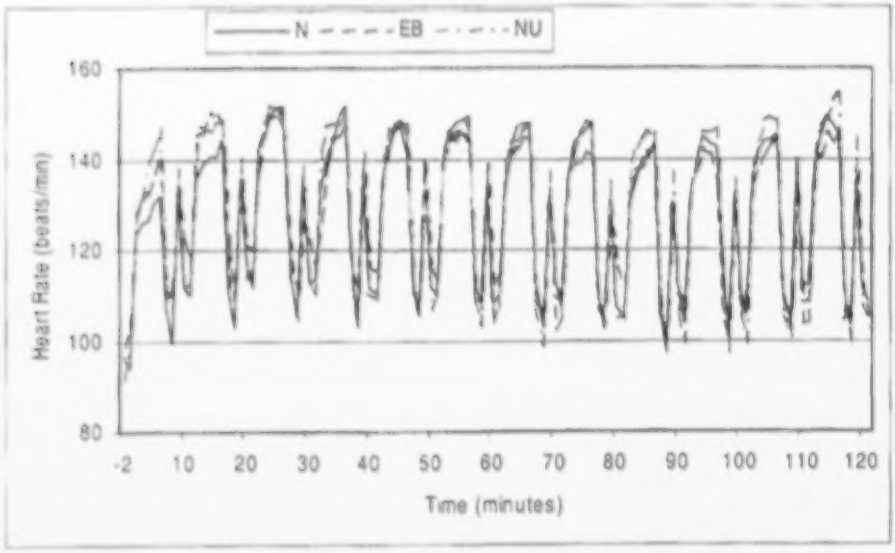

Figure 37: Average heart rate over time of all subjects in 18°C water while wearing one of three surfsuits.

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3.6 Metabolic rate

Average metabolic rate during arm paddling was 20.36, 24.76, 24.70 and 23.20 millilitres per kilogram per minute for Subjects 1 to 4 respectively which represents 5.64 times resting values. These values were derived from metabolic assessments performed during arm paddling within the first thirty minutes of exposure. These values represent sixty-five percent of each subject's VO_2 maximum as derived from their preliminary seated arm crank ergometer assessment.

3.7 Thermal comfort rating

Thermal comfort rating data are presented in Figures 38 to 41.

Thermal comfort ratings were lower in 13°C water. Thermal comfort ratings were lowest for EB and highest for NU. Thermal comfort ratings became constant after thirty-five minutes in 13°C water and after forty-five minutes in 18°C water.

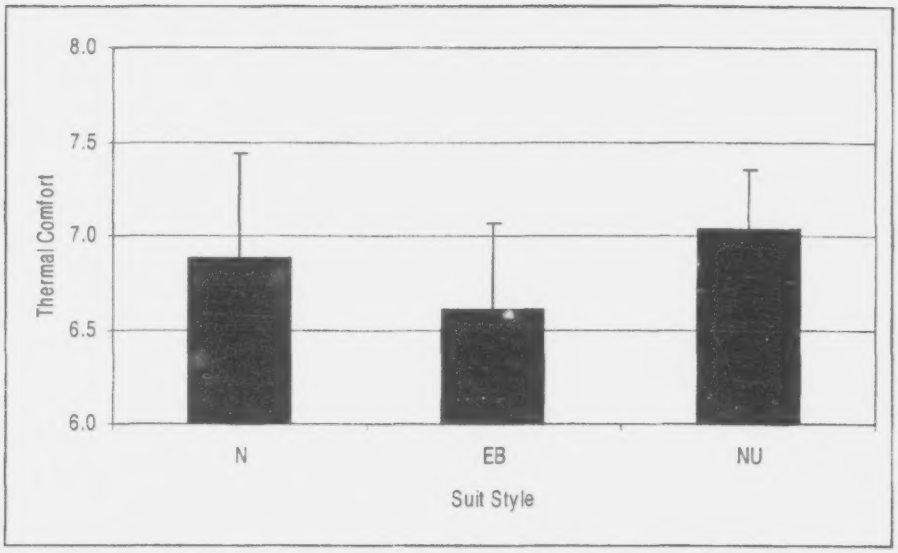

Figure 38: Average thermal comfort ratings of all subjects in 13°C water while wearing one of three surfsuits.

Figure 39: Average thermal comfort ratings of all subjects in 18°C water while wearing one of three surfsuits.

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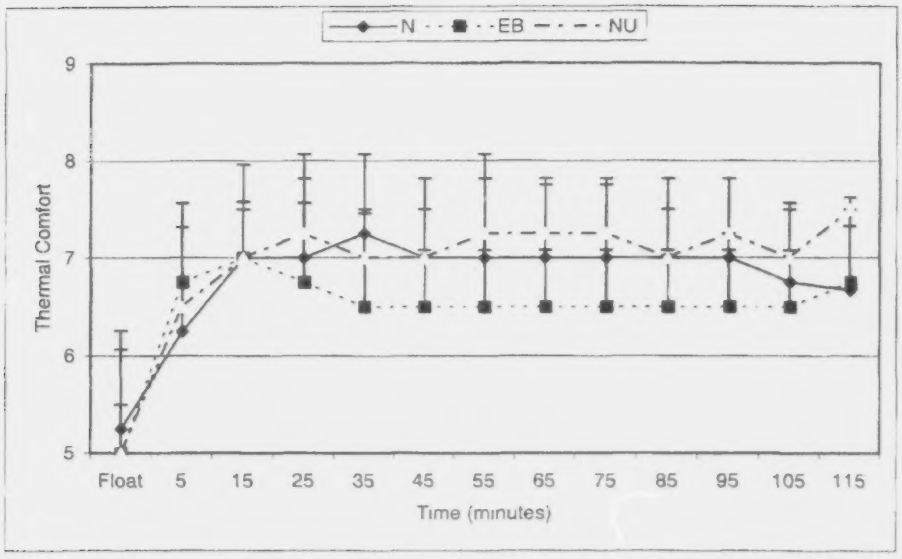

Figure 40: Average thermal comfort ratings over time of all subjects in 13°C water while wearing one of three surfsuits.

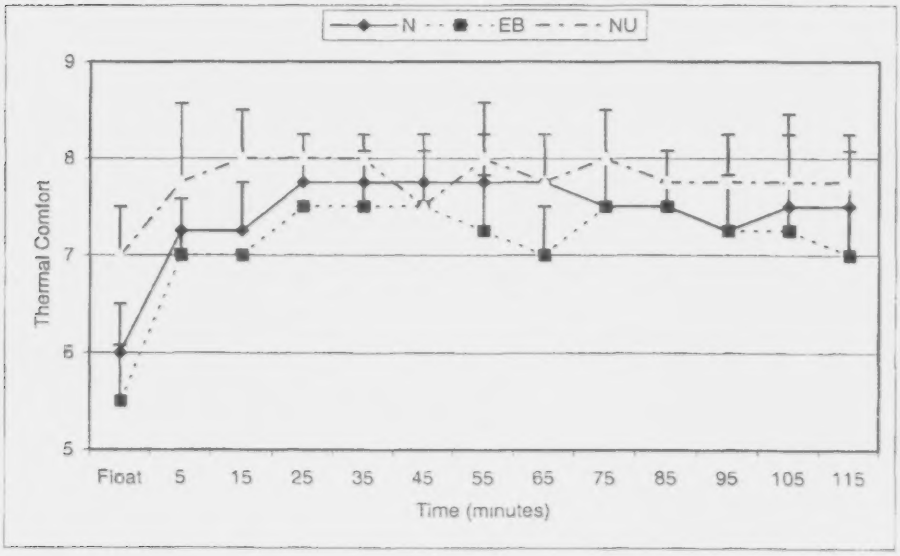

Figure 41: Average thermal comfort ratings over time of all subjects in 18°C water while wearing one of three surfsuits.

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3.8 Perceived exertion rating

Perceived exertion rating data are presented in Figures 42 to 45.

Perceived exertion ratings were similar between water temperatures. Perceived exertion ratings ascended faster over time in 18°C water. NU ratings were highest for the first seventy-five minutes. N ratings were lowest for the first forty-five minutes in 13°C water while EB ratings were lowest for the first seventy-five minutes in 18°C water.

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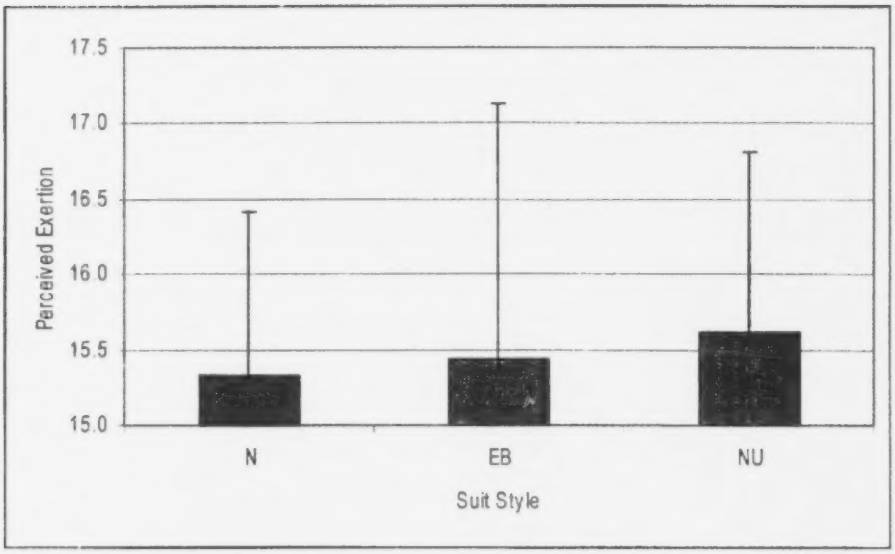

Figure 42: Average perceived exertion ratings of all subjects in 13°C water while wearing one of three surfsuits.

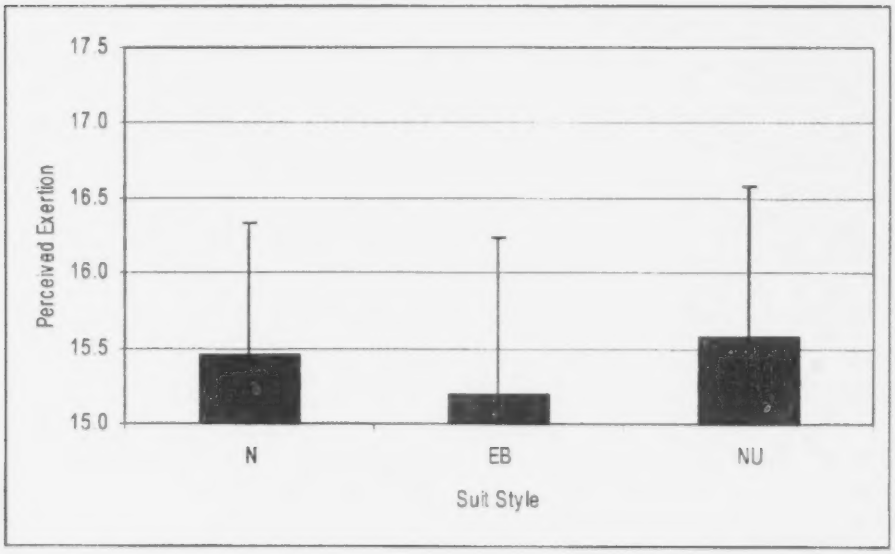

Figure 43: Average perceived exertion ratings of all subjects in 18°C water while wearing one of three surfsuits.

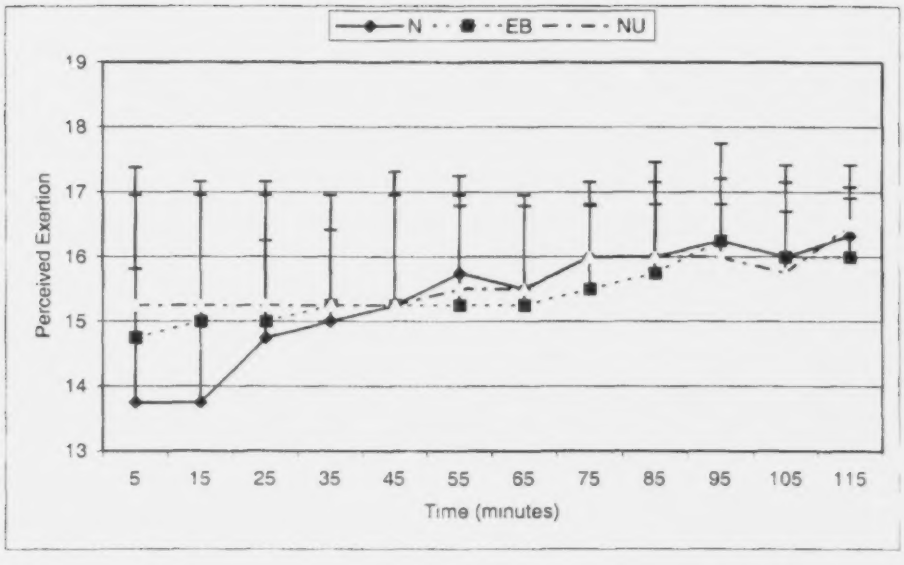

Figure 44: Average perceived exertion ratings over time of all subjects in 13°C water while wearing one of three surfsuits.

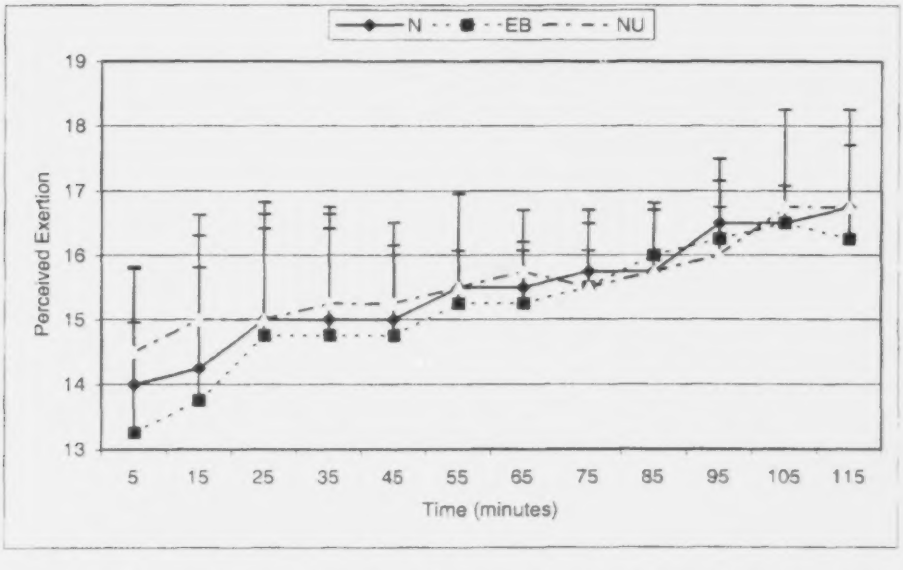

Figure 45: Average perceived exertion ratings over time of all subjects in 18°C water while wearing one of three surfsuits.

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3.9 Clothing insulation

Clothing insulation data are presented in Figures 46 and 47.

Clothing insulation was greater for NU regardless of water temperature.

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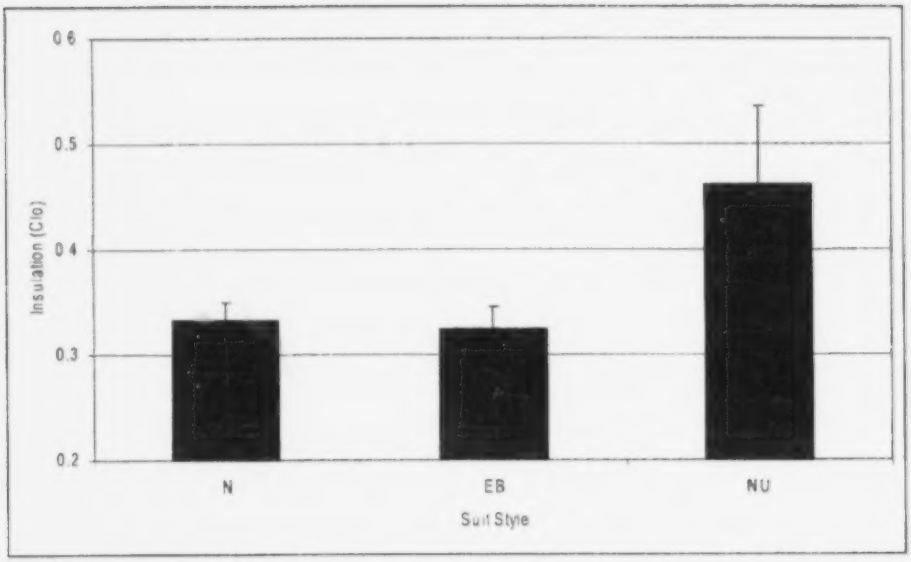

Figure 46: Average clothing insulation for all subjects in 13°C water while wearing one of three surfsuits.

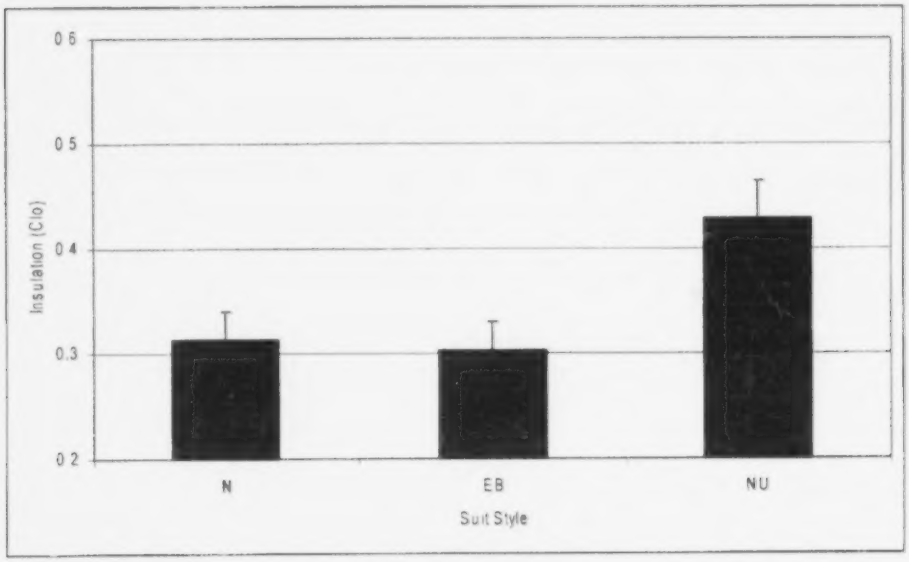

Figure 47: Average clothing insulation for all subjects in 18°C water while wearing one of three surfsuits.

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3.10 Environmental conditions

Environmental condition data are presented in Figures 48 to 51.

Average water temperature was 0.15°C higher for N in 13°C water. Average water temperature was 0.10°C lower for NU in 18°C water. These differences are negligible.

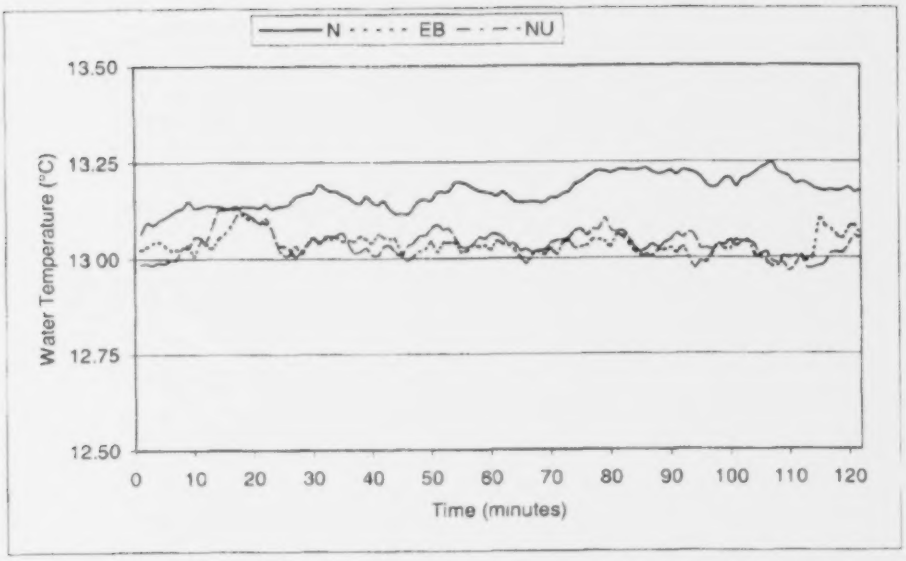

Figure 48: Average water temperature over time for all subjects in 13°C water while wearing one of three surfsuits.

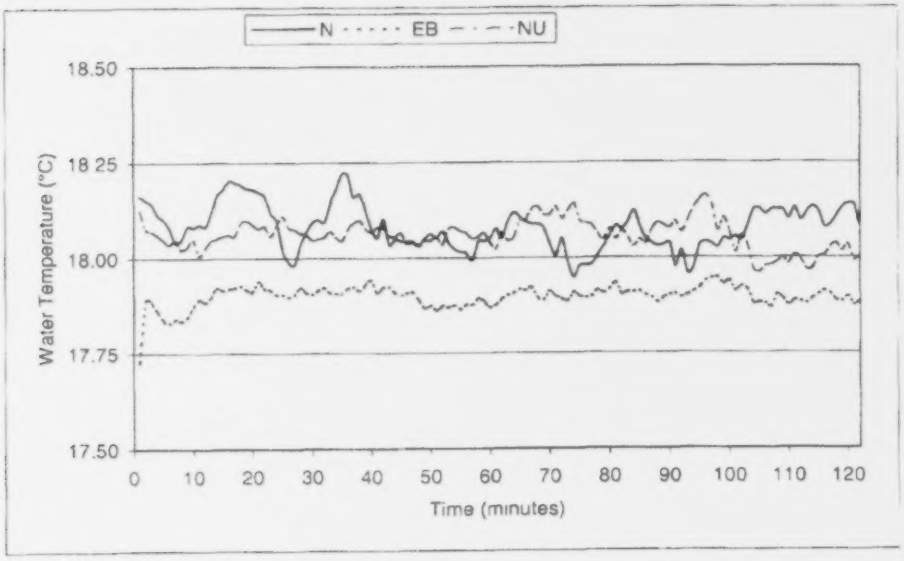

Figure 49: Average water temperature over time for all subjects in 18°C water while wearing one of three surfsuits.

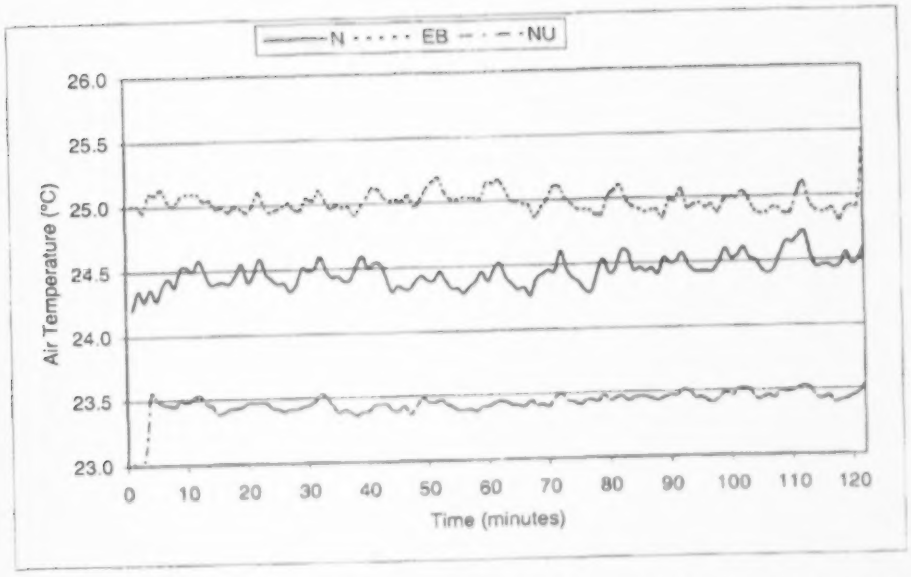

Figure 50: Average air temperature over time for all subjects in 13°C water while wearing one of three surfsuits.

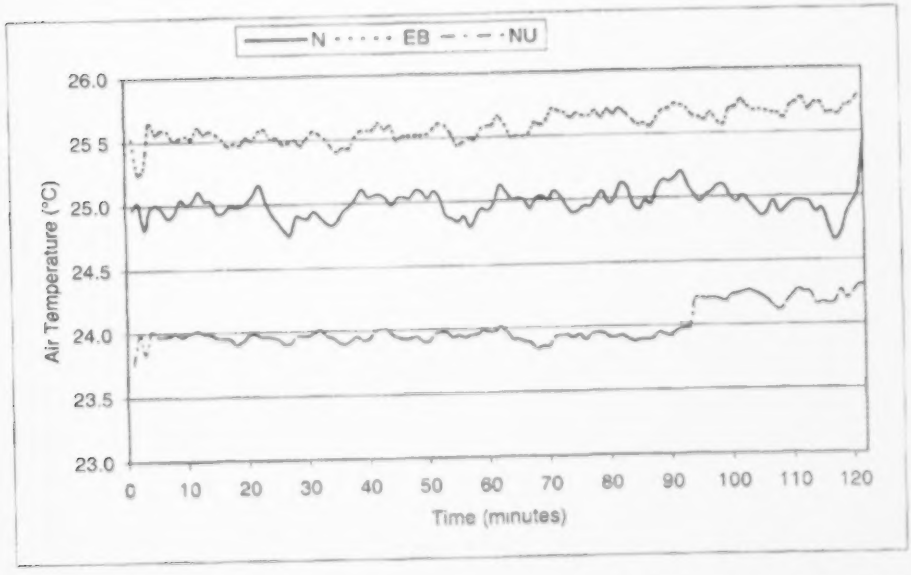

Figure 51: Average air temperature over time for all subjects in 18°C water while wearing one of three surfsuits.

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4. Discussion

The three surfsuits tested were designed to protect surfers in cool water temperatures between about 13°C and 20°C for a maximum amount of time. Environmental conditions were steady near 13°C and 18°C water with a 20 kilometre per hour wind with air temperatures between 23°C and 26°C directed along the water surface. Average metabolic rates during arm paddling were 5.64 times rest values and represent sixty-five percent of each subjects VO_2 maximum as derived from their preliminary seated arm crank ergometer assessment. Indoor air temperatures were beneficial to the heat storage of subjects and may have reduced heat flow values and increased skin temperature values as compared to ambient outdoor air temperatures.

Subjects perceived water moving within the suit as an important comfort factor. It was undesirable to have cool water move across the skin as it entered from the neck and cuff seals or up from the cooler, less active leg regions. All subjects complained of excess water movement within the torso region when EB was worn especially after arm paddling when immersed and treading water. All subjects also complained of excess water movement within the chest region when NU was worn. Surfing requires participants to arm paddle for five to fifteen minutes through oncoming waves requiring themselves and their surfboard to pass through the approaching waves – the effect of these inshore waves were attempted through the head dunking between activities and the prolonged treading water session. Subjects perceived the head dunks as refreshing.

Subjects perceived surfsuit fit and stretch as important comfort factors. Subjects complained NU was more resistant to their desired arm movements thereby requiring more muscular effort to arm paddle at the highest rates experienced with N and EB. These claims may be supported by the subjects higher perceived exertion ratings for the first twenty-five minutes and higher heart rates during the first and final arm paddling sessions regardless of water temperatures. NU heart rates in 13°C water were also highest during arm paddling but recovered fastest. Conversely, NU heart rates were lowest in 18°C water. Chest skin temperature values may be similar between conditions because of the greatest amount of water flushing inside the NU surfsuit chest area – the area noted by subjects to be a loose fit after the first five minutes of arm paddling. NU's inner arm panels were more resistant to the movements of the outer surfsuit as they were cut from an untested surfsuit previously laminated with neoprene fabric, which was mostly removed leaving neoprene foam exposed to the inner surfsuit tricot.

The effect of NU's additional insulation is profound considering a 5°C water temperature difference equated to a 3°C difference in average skin temperature. Covering twenty three percent of the subjects' average surface area with double insulation increased the suit mass from 1170 grams to 1920 grams while the suit positive buoyancy increased from 2370 grams to 3845 grams. Subjects perceived the

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increased positive buoyancy as beneficial during treading water sessions, which probably accounts for the lower heart rates during NU's treading water phases as subjects expended less effort to remain afloat. The thermal effects were equally promising. Thermal comfort ratings were highest for NU. The higher thermal comfort at low water temperatures is not associated to thermal discomfort at higher water temperature, nor higher heart rate nor perceived exertion. NU experienced higher and steadier rectal temperatures by 0.3 and 0.4°C in 13°C and 18°C water respectively. Average heat flux was about 30 to 50 watts per square metre lower for sensors under NU's additional insulation panels, except for chest and forehead, which were either similar or greater than other surfsuit values in 18°C water. Slightly higher forehead heat flows may have been expressions of higher core temperatures and greater heat storage or even the need to sweat. Skin temperatures were 2°C higher for NU for the double-insulated appendages and neck regions with torso values only 1°C higher.

The need for minimum leg insulation is apparent as EB posterior knee and posterior lower leg skin temperatures were 2°C cooler than all surfsuits. Low EB leg temperatures may be expressions of the 3.0mm thick neoprene with normal inner fabric or the 2.5mm short-loop neoprene used over these sites. Thermal comfort ratings were also lowest for EB. EB external suit temperatures were cooler than other suits in 18°C water. Perceived exertion ratings were lowest for the first seventy-five minutes in 18°C water possibly due to the decreased amount of insulation thickness and increased flexibility. The characteristics of EB emphasise the amount of insulation and energy expenditure required for comfort.

Recommendations include a field trial of greater subject numbers in ambient conditions. It would be necessary and possible to waterproof the instrumentation and use data loggers. Special care should be given to subject selection to ensure all surfing abilities within the product market focus and all body types within the pattern sizing are used as experimental subjects.

Even though the attained paddling cadences are realistic, the one limitation of the NU surfsuit is the increased perceived effort of the medial and posterior deltoids to maintain an arm paddling cadence above nine pairs of left and right arm movements every ten seconds. Singular panels of six-millimetre, hyperstretch neoprene would improve design rather than two, ill-fitting layers of neoprene where the outer surfsuit stretches over the trapped inner panel's exposed neoprene foam. Attention to panel placement and assembly could drastically improve fit and flexibility to N or EB characteristics. Every surfsuit tested would benefit from either a greater stretch ability of the neoprene beneath the arm or a greater length of neoprene added to the cut of the necessary underarm panels. The potential for the length of neoprene available to stretch when needed over the chest, shoulder, armpit, lateral torso and inner upper arm is so great that range of motion within this region should be a design feature rather than a limitation.

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5. Conclusion

Physiologically, NU was the most thermally comfortable followed by N then EB under the conditions tested. Subjectively, participants preferred NU for thermal comfort and increased buoyancy but disliked it for perceived exertion although this perception does not seem different except for the first twenty-five minutes. N and EB were more similar to each other than either was or both were to NU. NU would be favourable in a manufactured fit and finish.

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6. References

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2. Dubois, D and E. F. Dubois. A formula to estimate the approximate surface area if height and weight be known. Arch. Int Med. 17:863-871, 1916.

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Annexes

Thermal comfort rating scale

1	so cold I am helpless
2	numb with cold / pain
3	very cold
4	cold
5	cool and uncomfortable
6	cool but comfortable
7	comfortable
8	warm but comfortable
9	warm and uncomfortable
10	hot
11	very hot
12	almost as hot as I can handle
13	so hot I am sick and nauseated

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Perceived exertion rating scale

6	very very light
7	
8	very light
9	
10	fairly light
11	
12	somewhat hard
13	
14	hard
15	
16	very hard
17	
18	very very hard
19	

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List of abbreviations

DND	Department of National Defence
DRDC	Defence Research and Development Canada
DCIEM	Defence and Civil Institute of Environmental Medicine
°C	degree Celsius
NU	non-uniform insulation surfsuit
EB	enhanced boundary surfsuit
N	normal surfsuit
W/m^2	watts per square metre
yr	year
cm	centimeter
kg	kilogram
m^2	square meter
VO_2 max.	maximal volume of oxygen consumed
l/min	liter per minute
ml/kg/min	millilitre per kilogram per minute
%	percent
Clo	clothing insulation

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Steven J. Davies, Michel B. Ducharme

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14 ABSTRACT

(U) Salomon's Advanced Research Clothing Division contracted DCIEM to assist in development and evaluation of technical surfsuits by defining the thermal insulation properties of surfsuit prototypes and the main heat loss areas during simulated surfing activity. Thermal characteristics will be evaluated by Salomon to design future surfsuits with different insulations according to heat storage and surfing activities. DCIEM tested three prototype surfing wetsuits for thermal characteristics in two water temperatures. Each surfsuit differed in amount and location of insulation, which would affect their capacity to retain heat. Four male subjects volunteered to test six conditions between August and December 2001. Each condition included one of two water temperatures (13°C and 18°C) and one of three surfsuits during simulated surf activities. After 2 minutes of floating rest, subjects experienced 120 minutes exposure of which 72 minutes were prone arm paddling on a tethered surfboard, 24 minutes were treading water and 24 minutes were immersed rest. Arm paddling metabolic rates averaged 5.64 times rest values. Sweat accumulation was never a concern. Surfsuit fit and water movement inside the surfsuit were considered important comfort factors. NU experienced the best physiological and thermal responses but subjects complained of increased muscular effort for the posterior and medial deltoids when the non-uniform surfsuit was worn. EB was coolest especially for the lower leg but perceived exertion ratings were lowest among surfsuits due to thinner neoprene fabrics. N was similar to the enhanced boundary surfsuit yet provided marginally better protection. NU had highest rectal temperature by 0.4°C and 0.3°C in 13°C and 18°C water respectively. Subjects were slightly hypothermic after wearing N and EB in 13°C water. Average heat flux was between 30 to 50 W/m2 lower for sensors under NU's additional insulation panels except for chest, which was similar in 18°C water. Skin temperatures were 2°C higher for NU's double-insulated appendages and neck regions with other torso values 1°C higher. Thermal comfort ratings were lowest for EB and highest for NU. NU ratings of perceived exertion were highest for the first twenty-five minutes. Clothing insulation was greater for NU regardless of water temperature.

15. KEYWORDS, DESCRIPTORS or IDENTIFIERS

(U) immersion suit; hypothermia; cold water; water activity; surf board